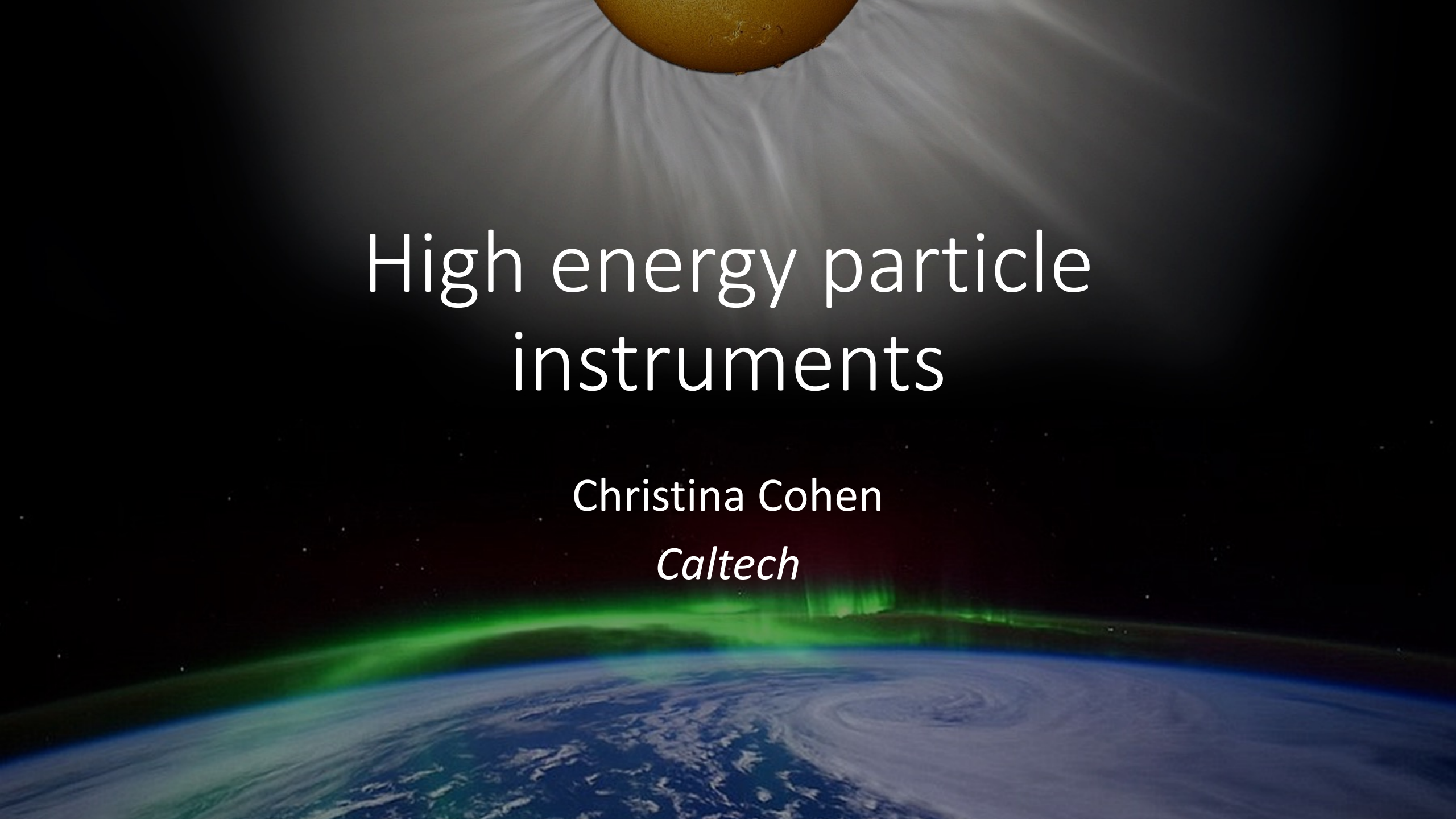


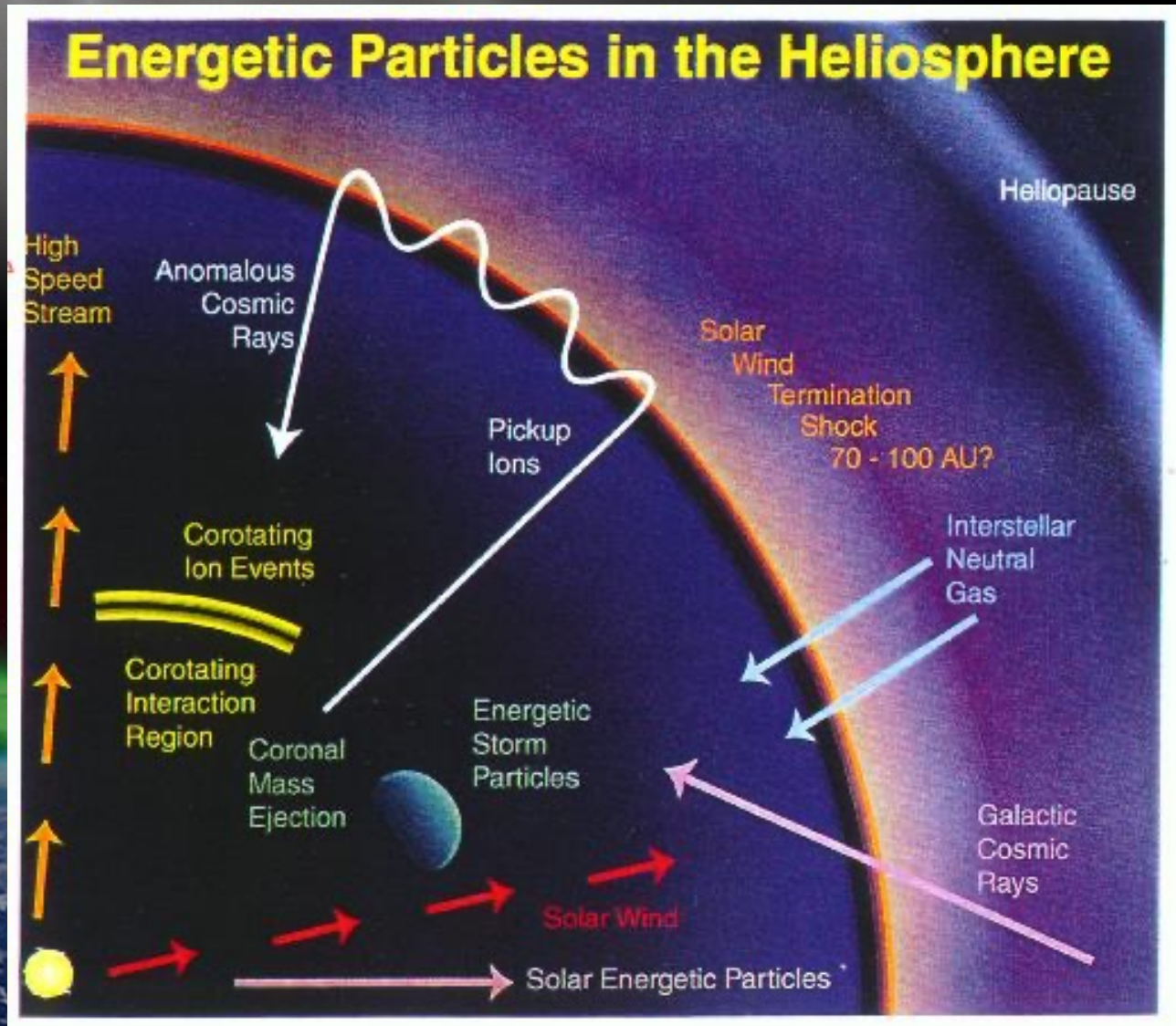
High energy particle instruments

Christina Cohen

Caltech

What do we want to measure?

- Energetic particles
  - Solar (SEPs)
  - Suprathermals (still SEPs)
  - Cosmic rays (GCRs, ACRs)
  - Corotating interaction region (CIR) particles
- Basic properties
  - Energy or velocity
  - Mass (species)
  - Ionic charge state
  - Intensities
- Why – see previous lecture



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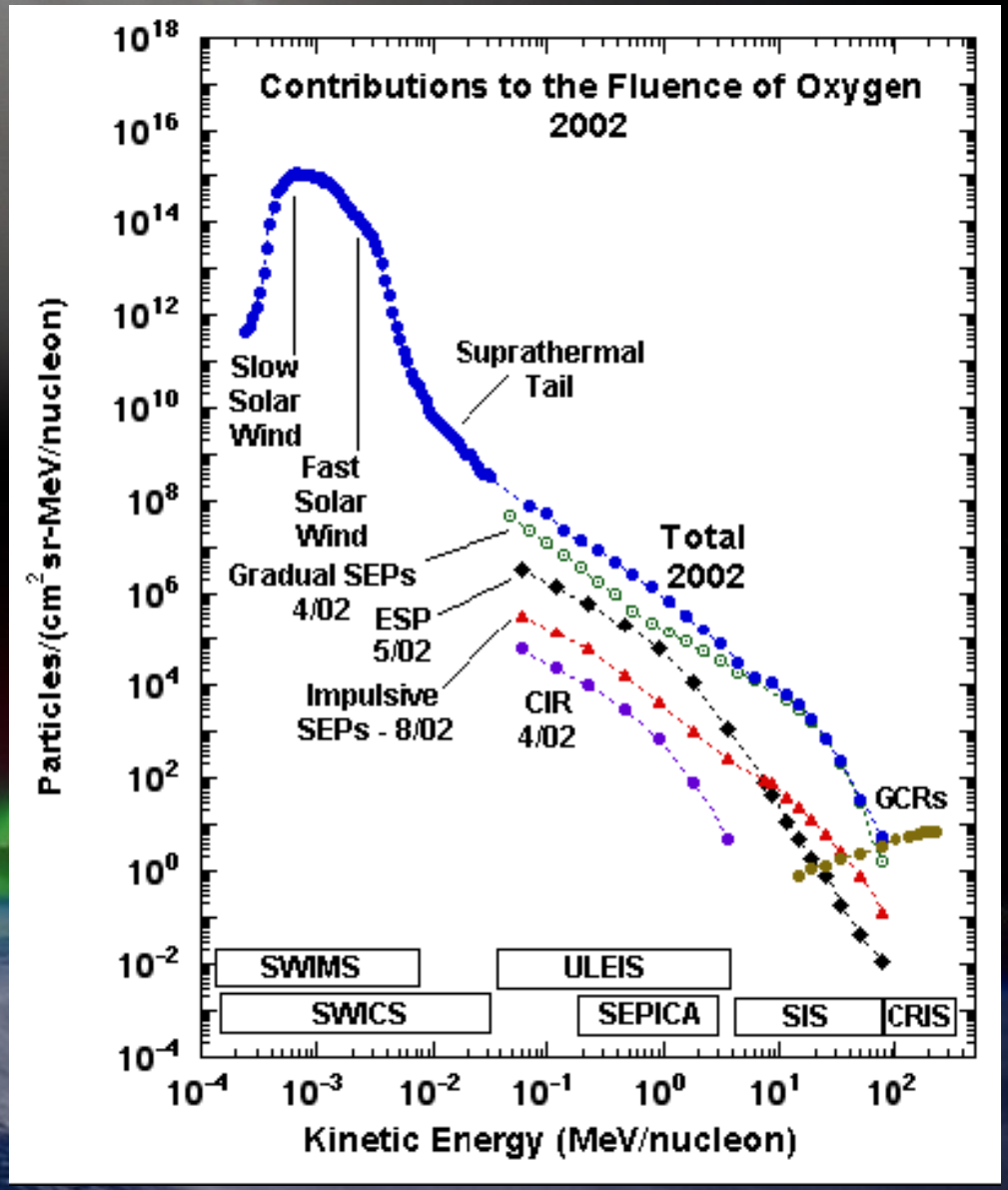


Difficulties

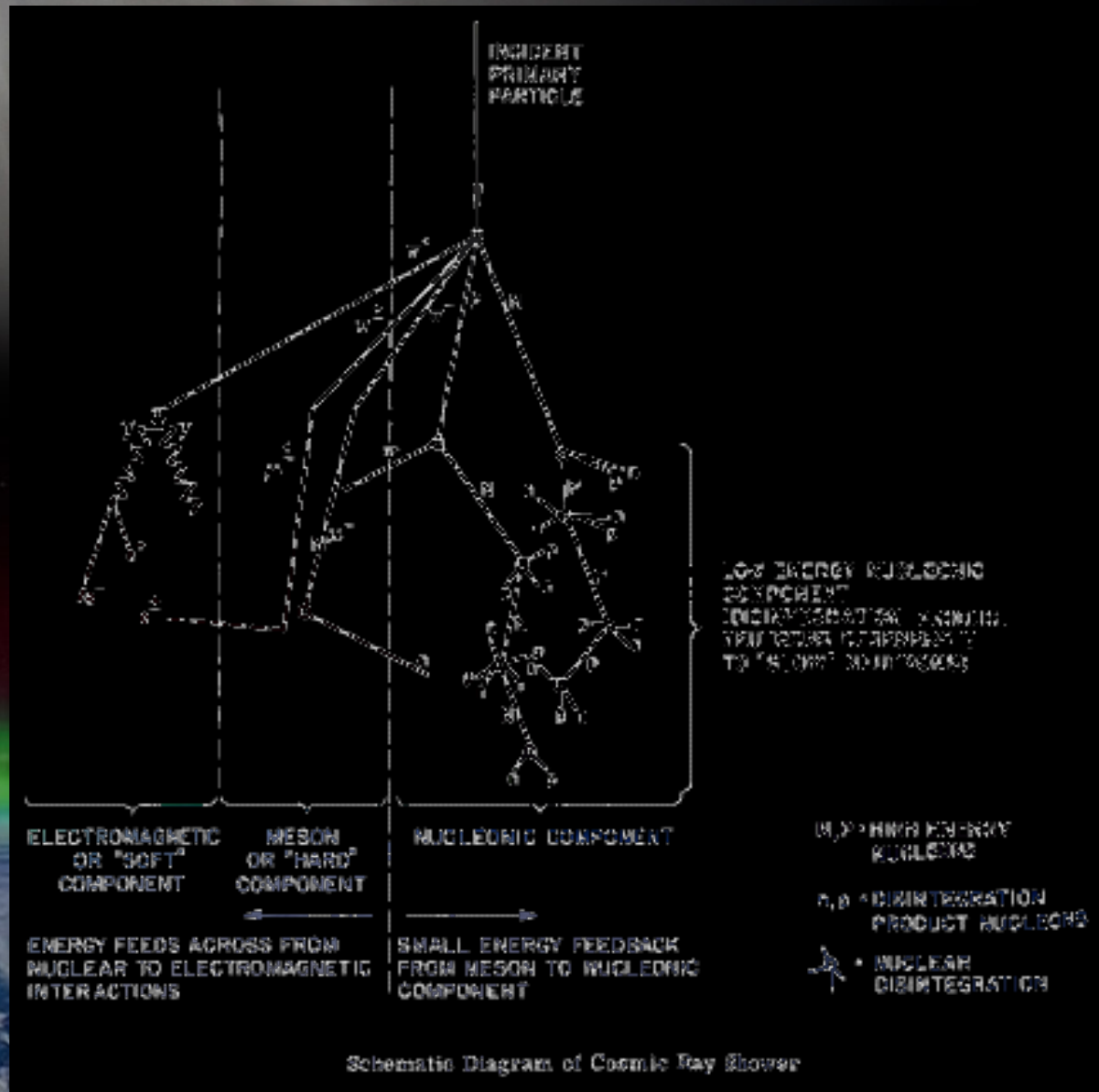
- Large energy range
  - Multiple instruments (intercalibration)
- Large intensity variations
  - Limit what you look at
  - Choose instrument based on most desirable
- Limited spacecraft resources
  - Mass, power, telemetry

How are SEPs Measured?

- On the ground
  - neutron monitors / muon detectors
- In space (since early 1960s)
  - first measurements (scintillation and Geiger counters)
  - dE/dx vs E’ technique
  - Time of flight
- Charge states
  - E/q + dE/dx vs E’
  - Geomagnetic filter

Neutron monitors / Muon detectors

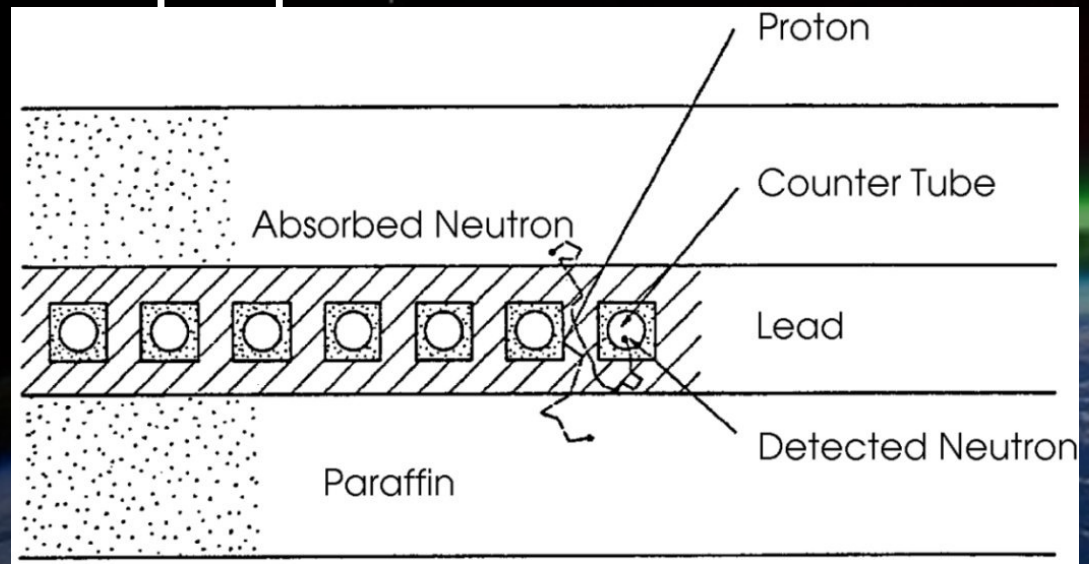
- Method
  - Particles interact with Earth atmosphere



Schematic Diagram of Cosmic Ray Shower

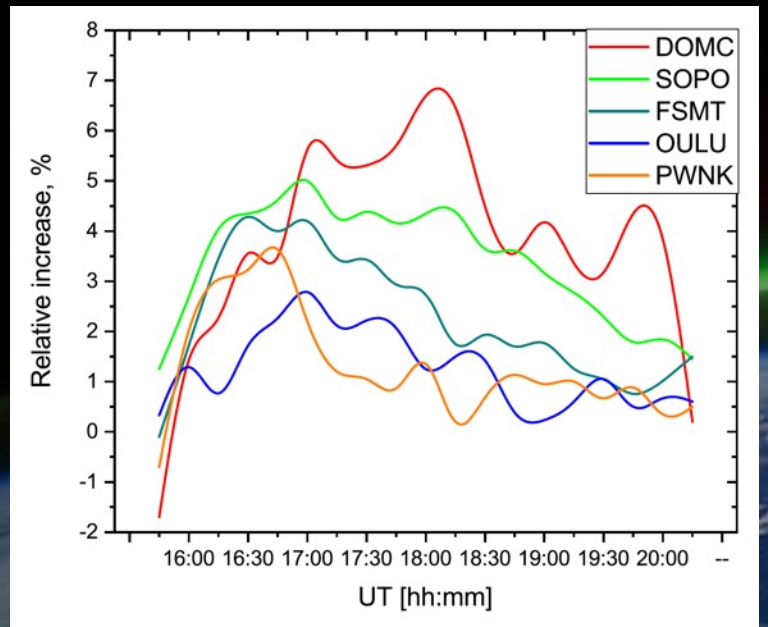
Neutron monitors / Muon detectors

- Method
  - Particles interact with Earth atmosphere
  - Neutrons measured by proportional counters



Neutron monitors / Muon detectors

- Advantages
  - Easy to install/maintain (on the ground)
  - Relatively inexpensive
  - Multiple locations provides info



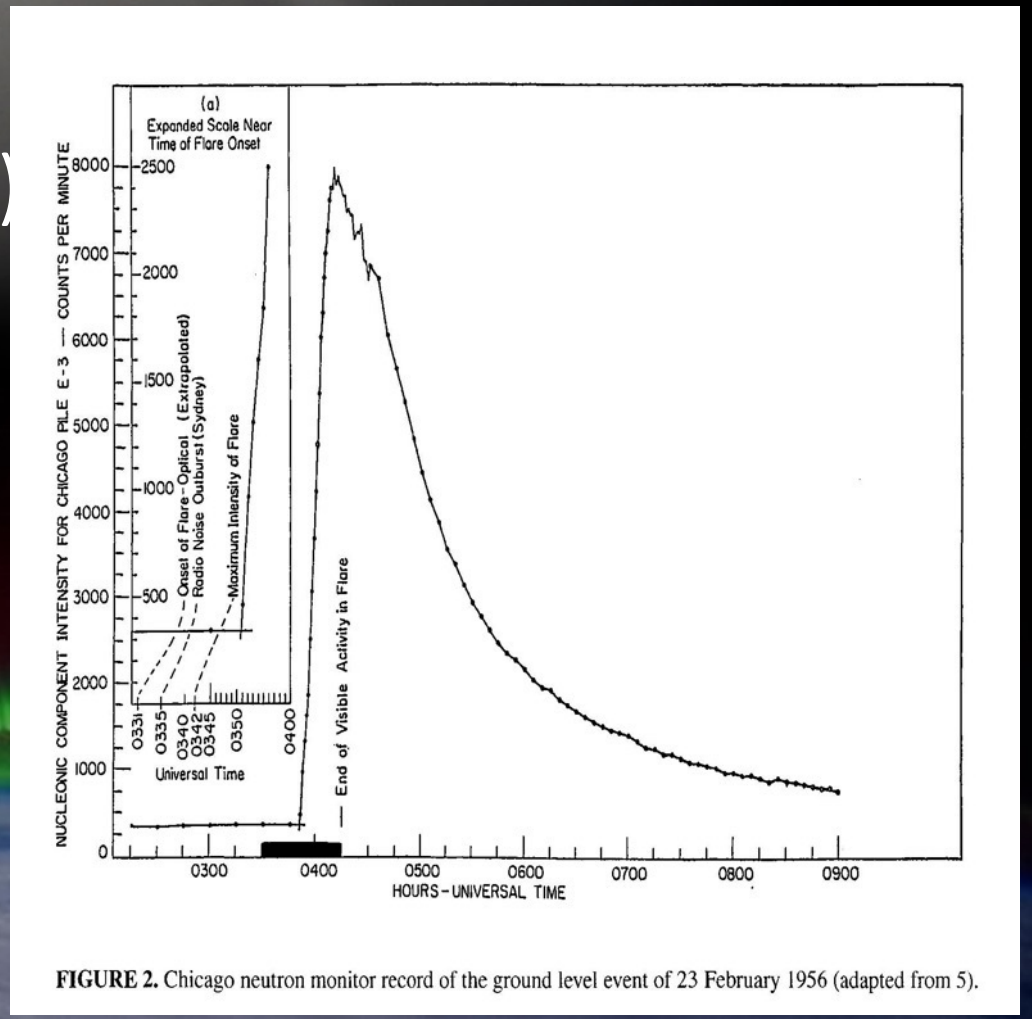
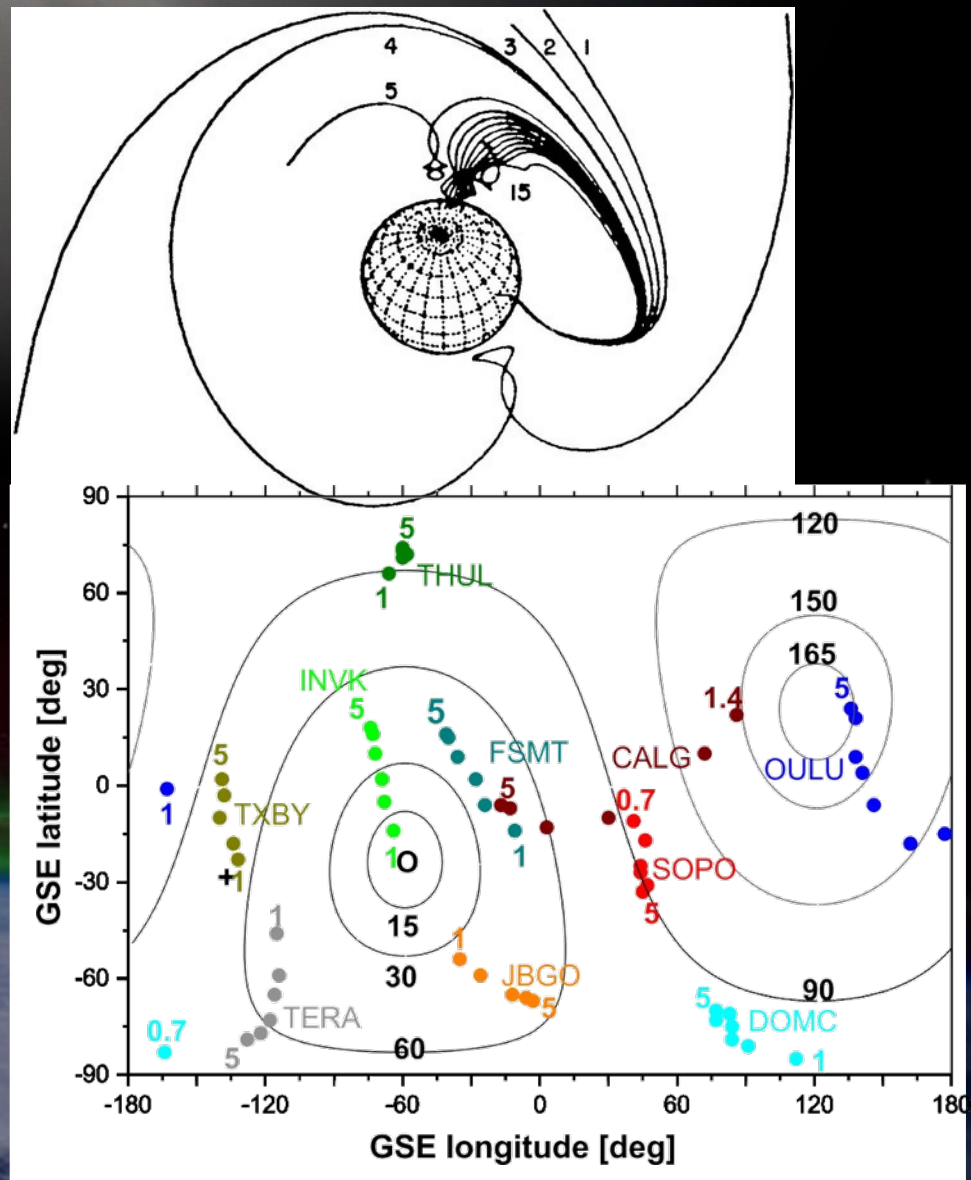


FIGURE 2. Chicago neutron monitor record of the ground level event of 23 February 1956 (adapted from 5).

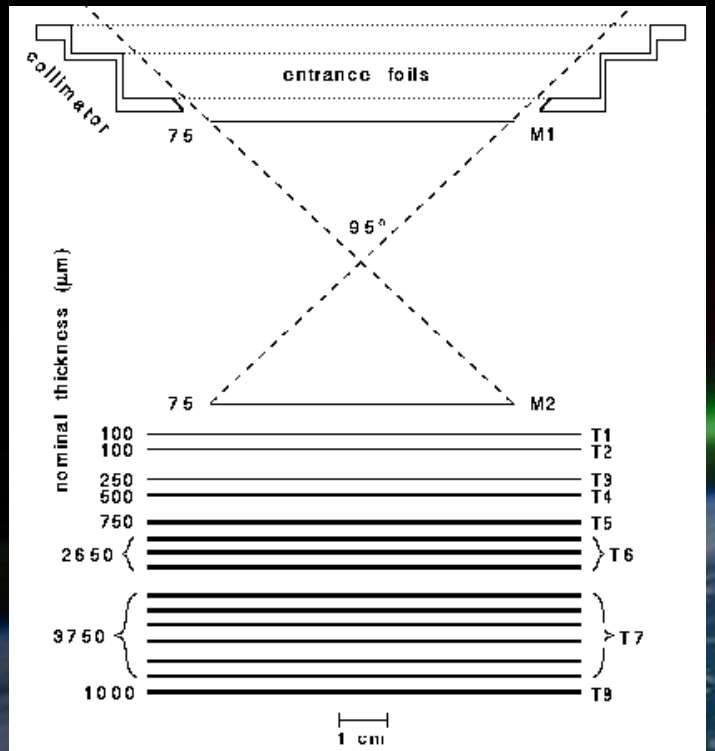
Neutron monitors / Muon detectors

- Advantages
  - Easy to install/maintain (on the ground)
  - Relatively inexpensive
  - Multiple locations provides info
- Disadvantages
  - Cannot distinguish species (mostly protons)
  - Complicated physics to account for transmission
  - High energy only > ~500 MeV



Silicon stack detectors (dE vs E')

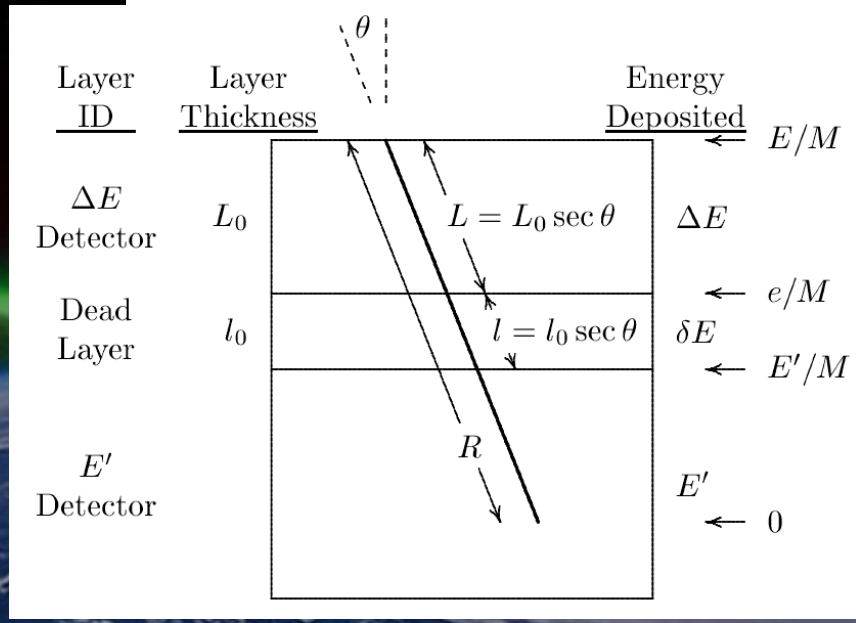
- Method
  - Particles interact with silicon and deposit energy
  - Tracks separate by Z and M

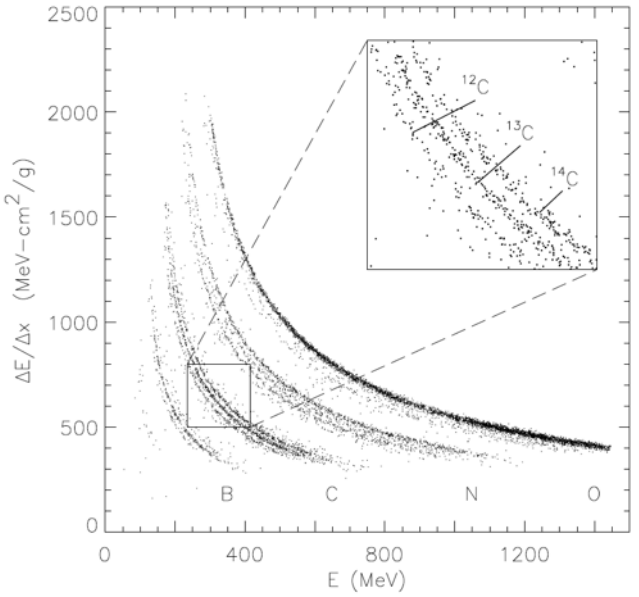


$$dE/dx \propto (Z/V)^2 \propto (MZ^2/E)$$

$$E\ dE/dx \propto Z^2M$$

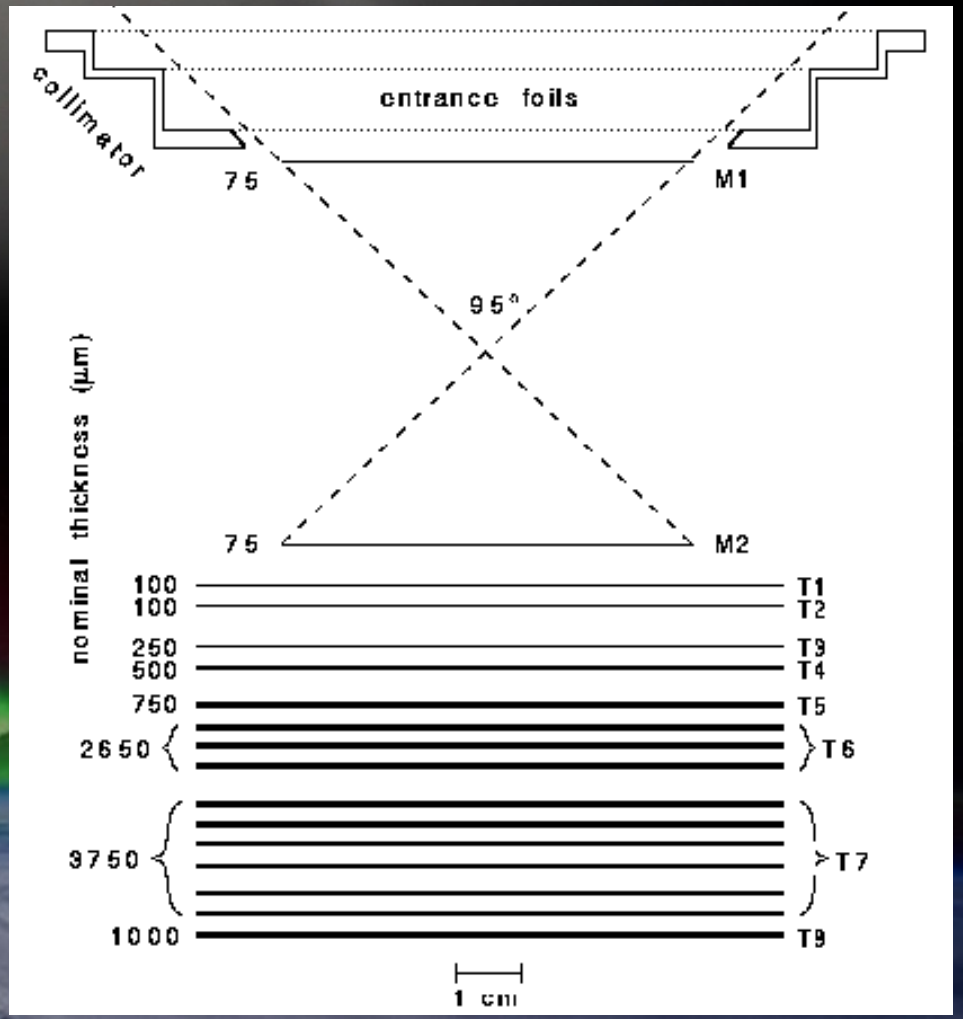
$$dE/dx \sim \Delta E/\ L = \Delta E/(L_0 \sec \vartheta)$$





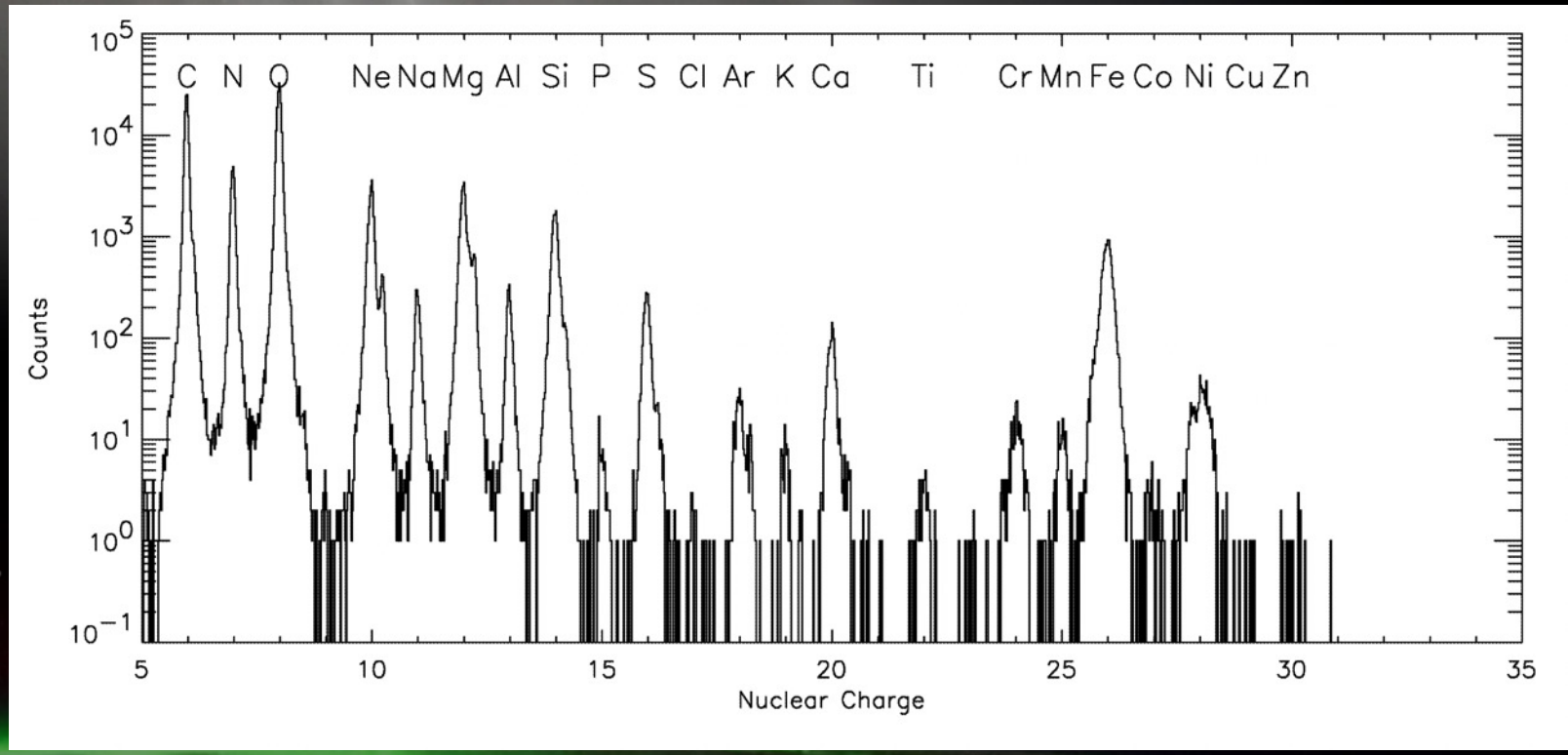
Silicon stack detectors (dE vs E')

- Method
  - Particles interact with silicon and deposit energy
  - Tracks separate by Z and M
  - Stack to get range of energies



Silicon stack detectors (dE vs E’)

- Advantages
  - Elements
  - Isotopes possible
  - Pretty robust



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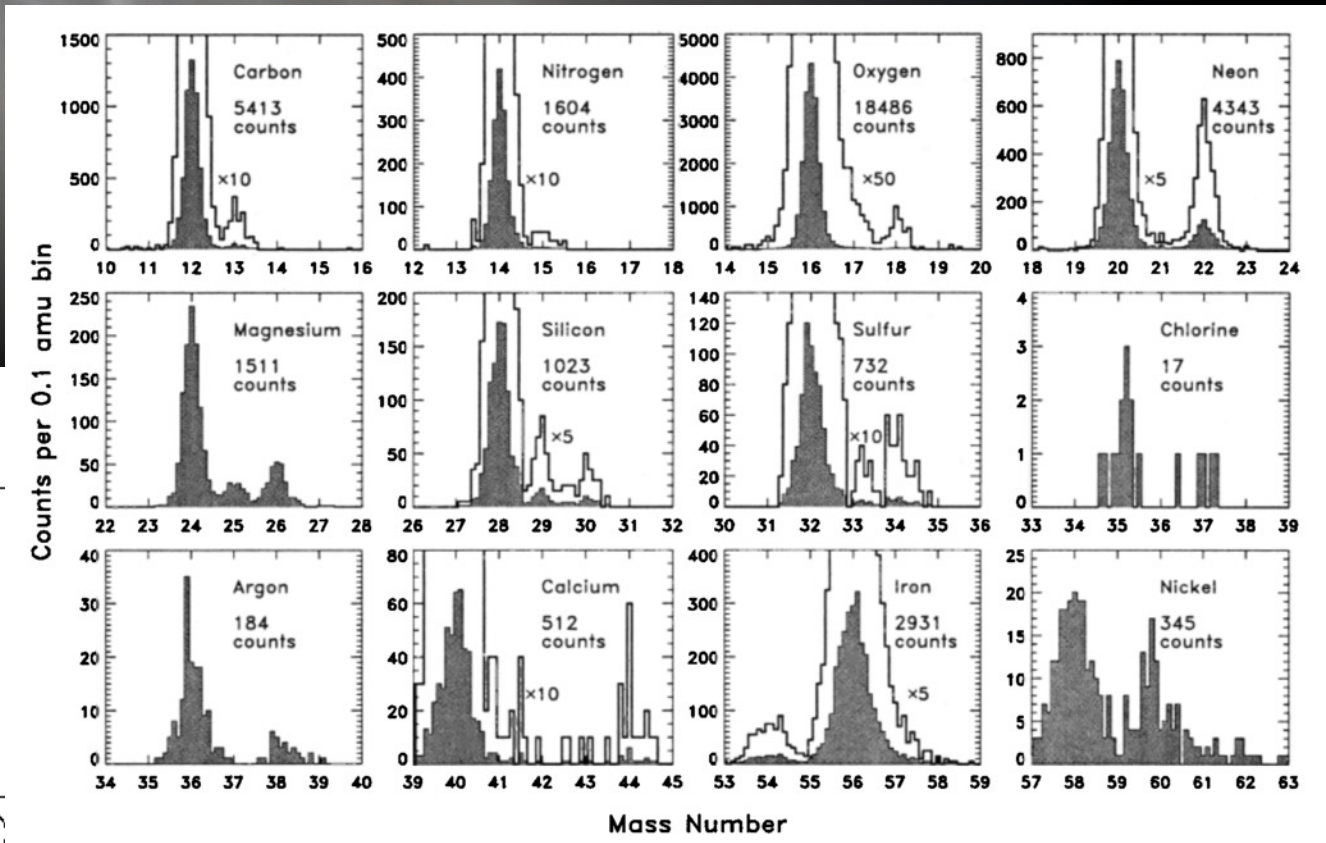
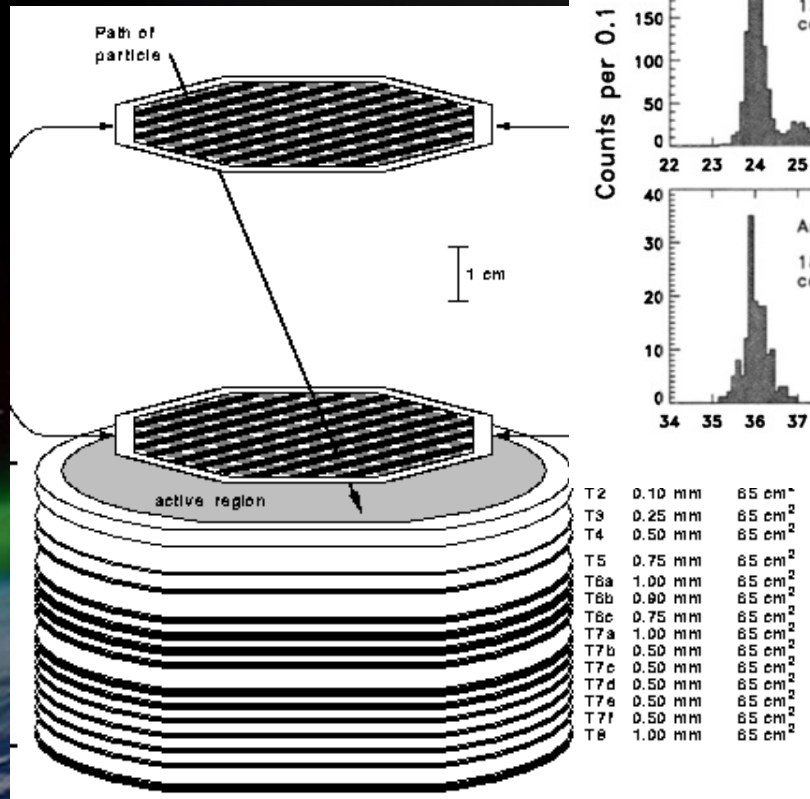
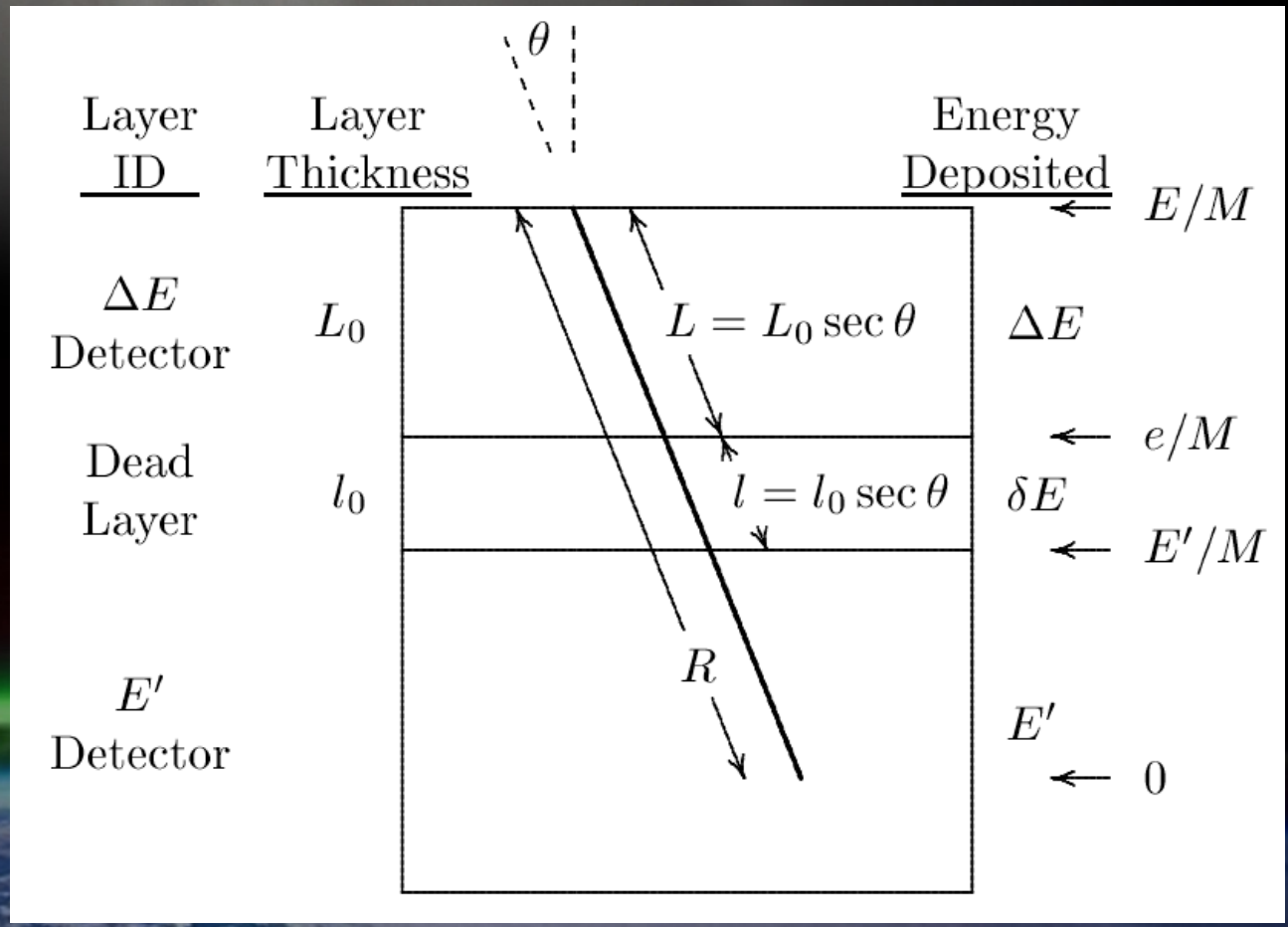




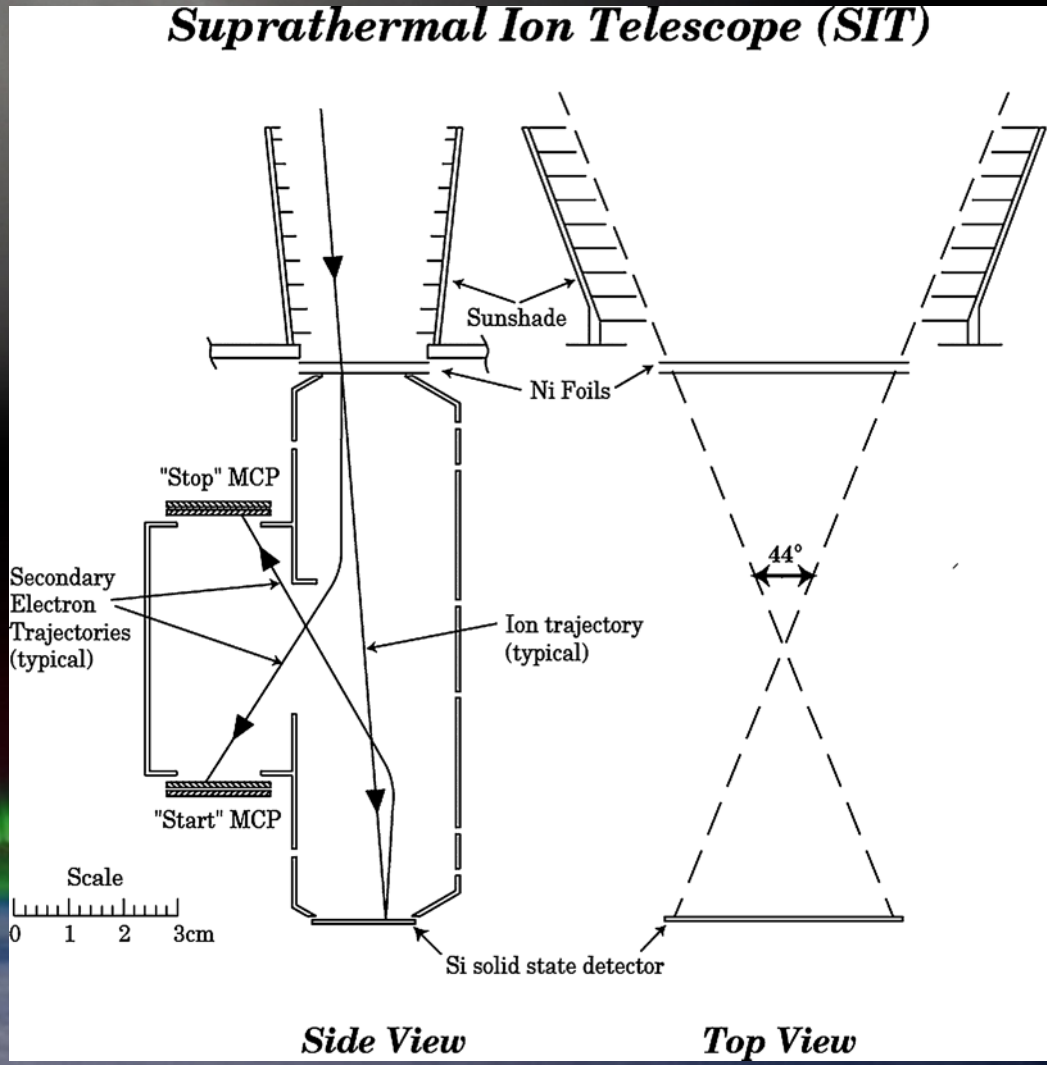
Silicon stack detectors (dE vs E')

- Advantages
  - Elements
  - Isotopes possible
  - Pretty robust
- Disadvantages
  - In space, so can't fix
  - Telemetry dependent
  - Low energies is hard



Time of flight (TOF)

- Method
  - Measure the time it takes to travel known distance and total energy
  - Multiple TOFs to check consistency



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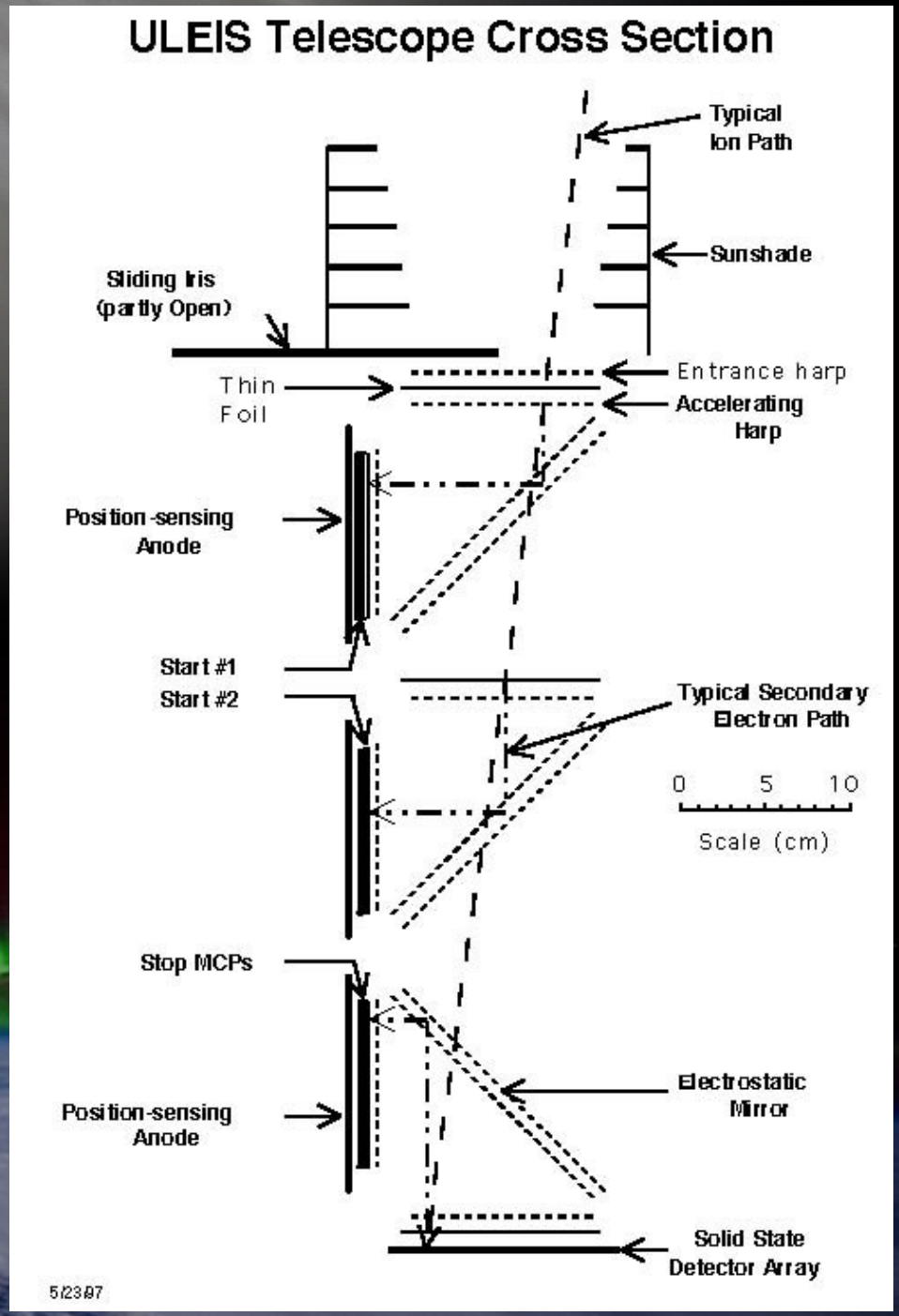
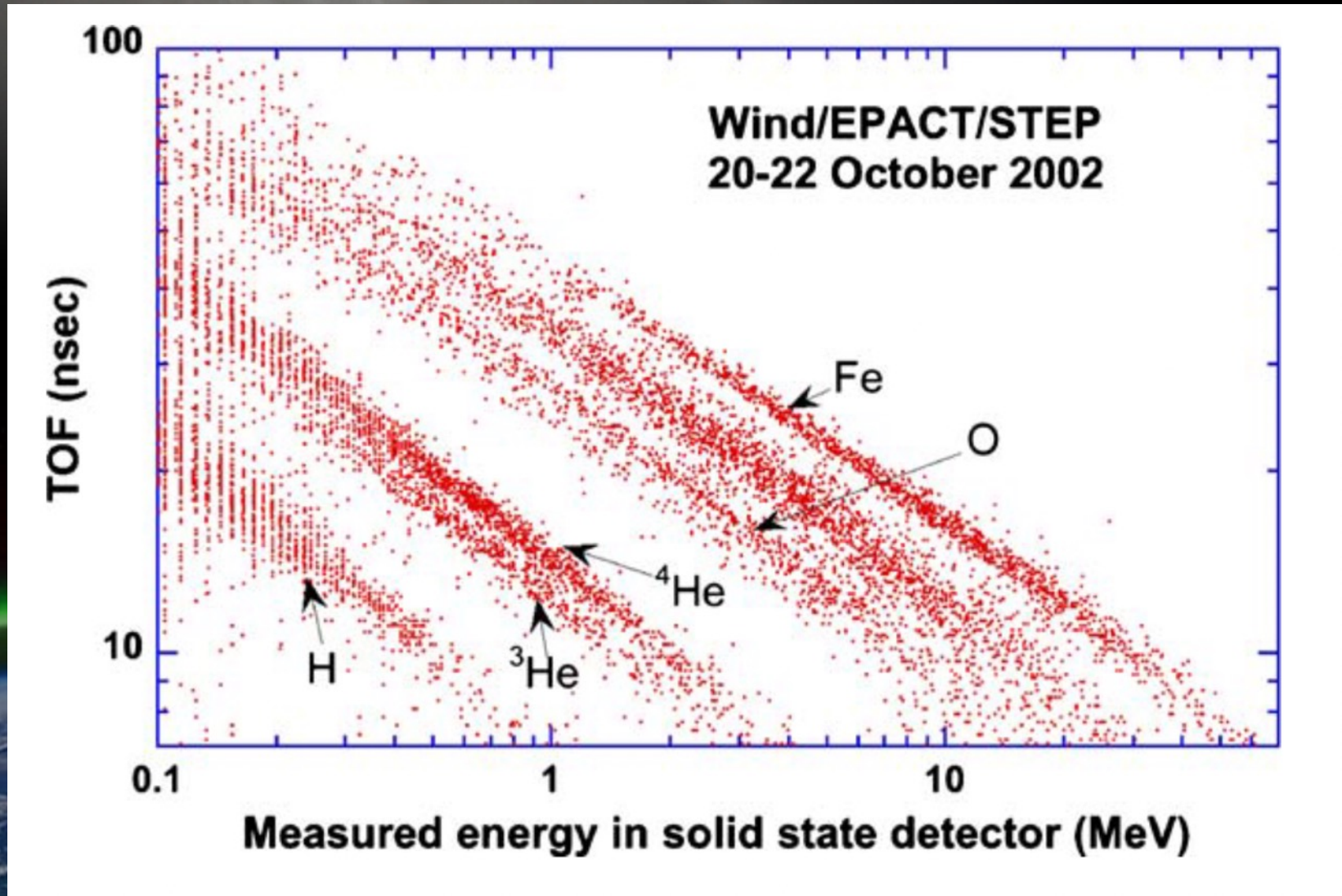


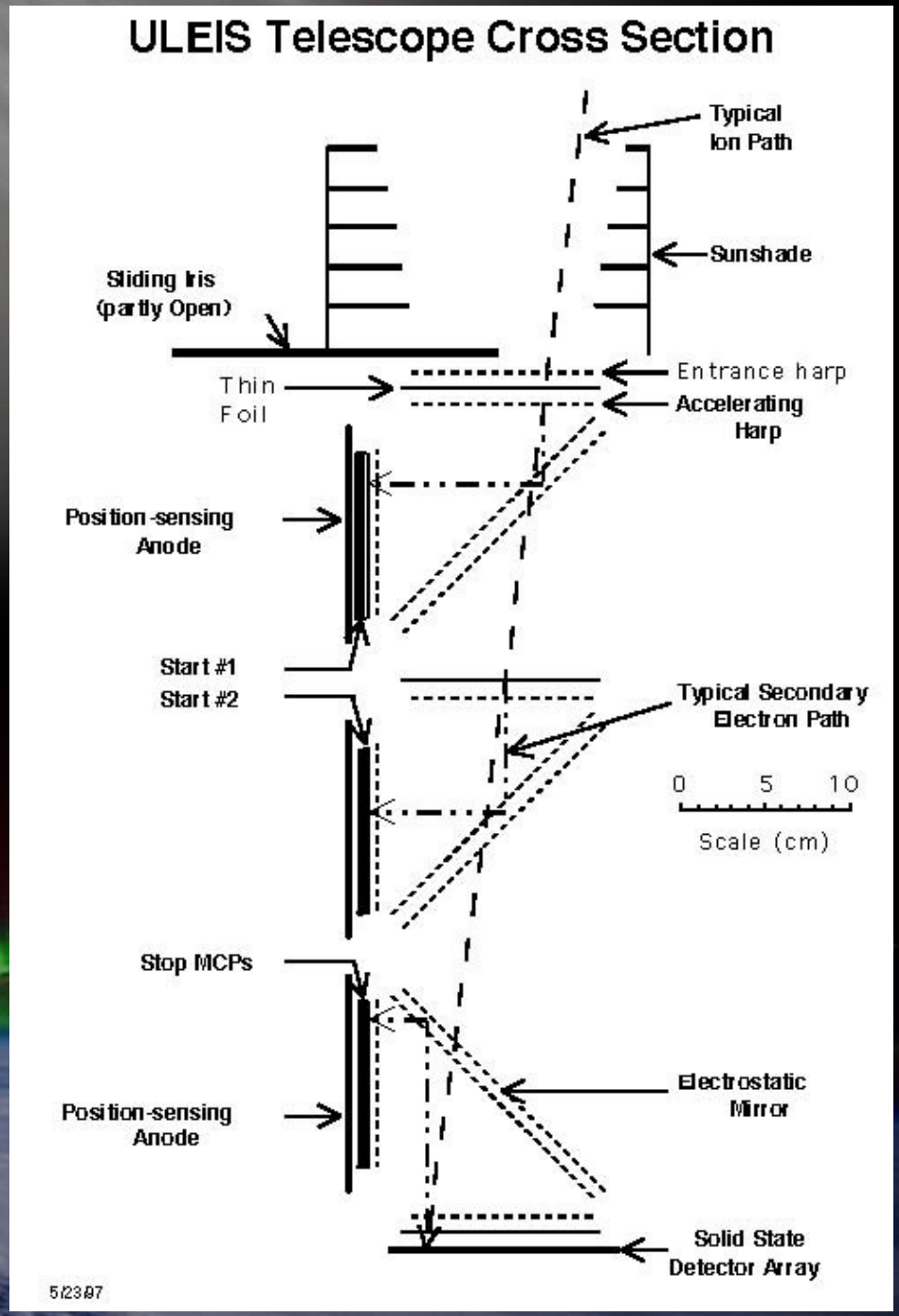
Time of flight (TOF)

- Advantages
  - Elements
  - Isotopes possible



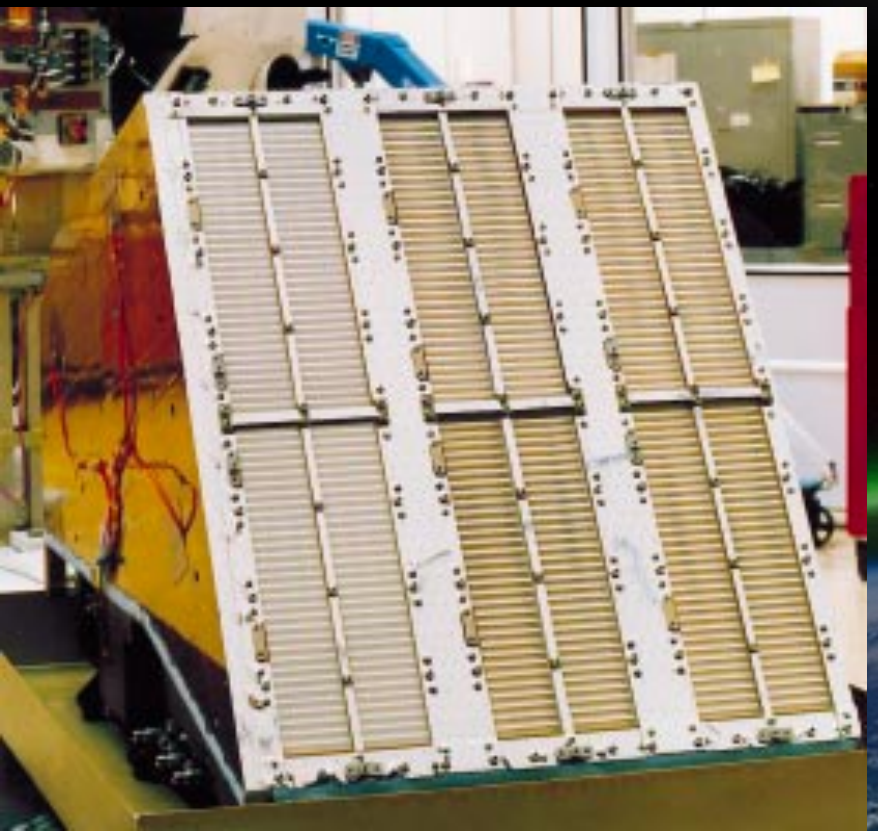
Time of flight (TOF)

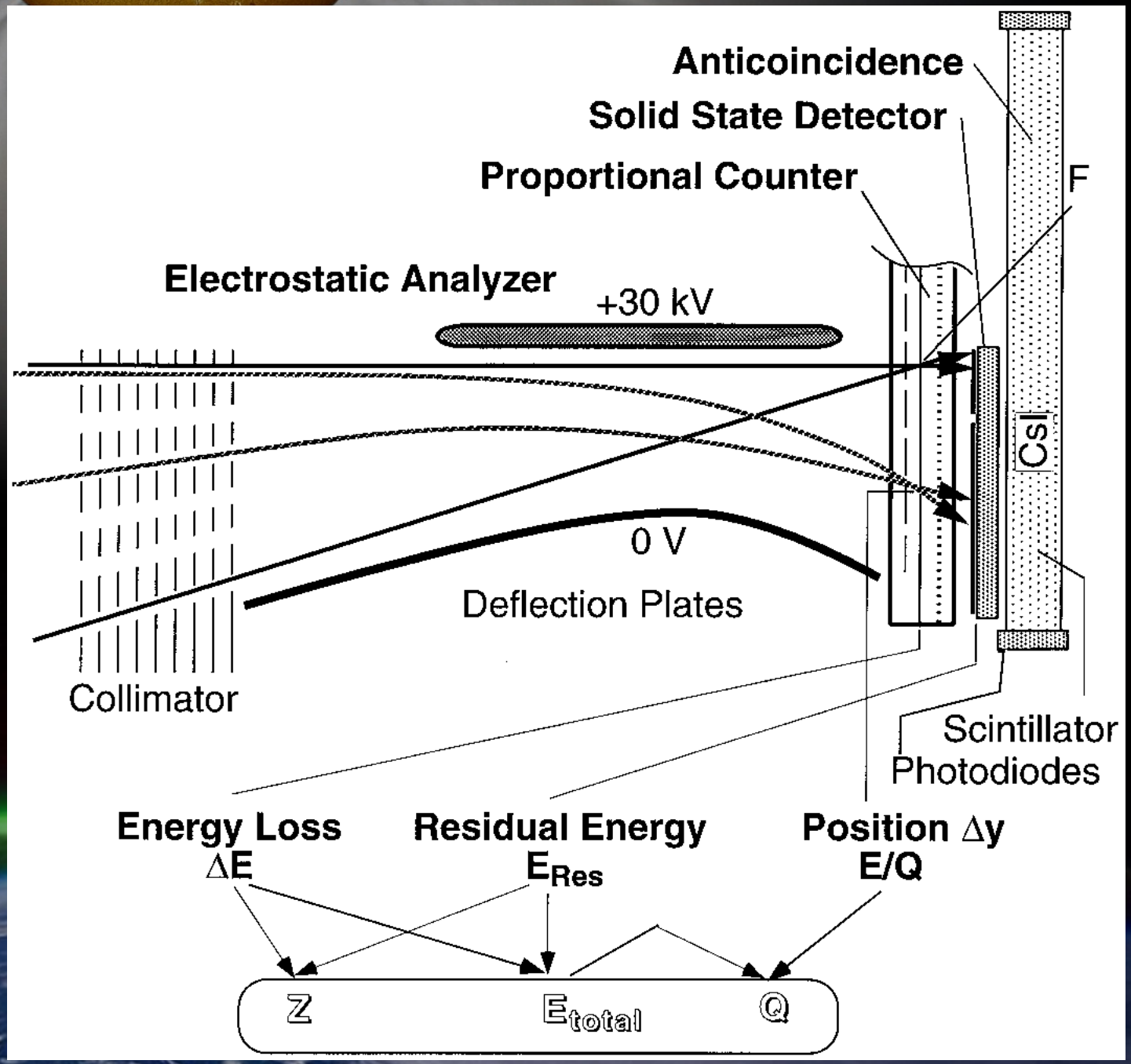
- Advantages
  - Elements
  - Isotopes possible
- Disadvantages
  - Foils can be fragile



Charge states

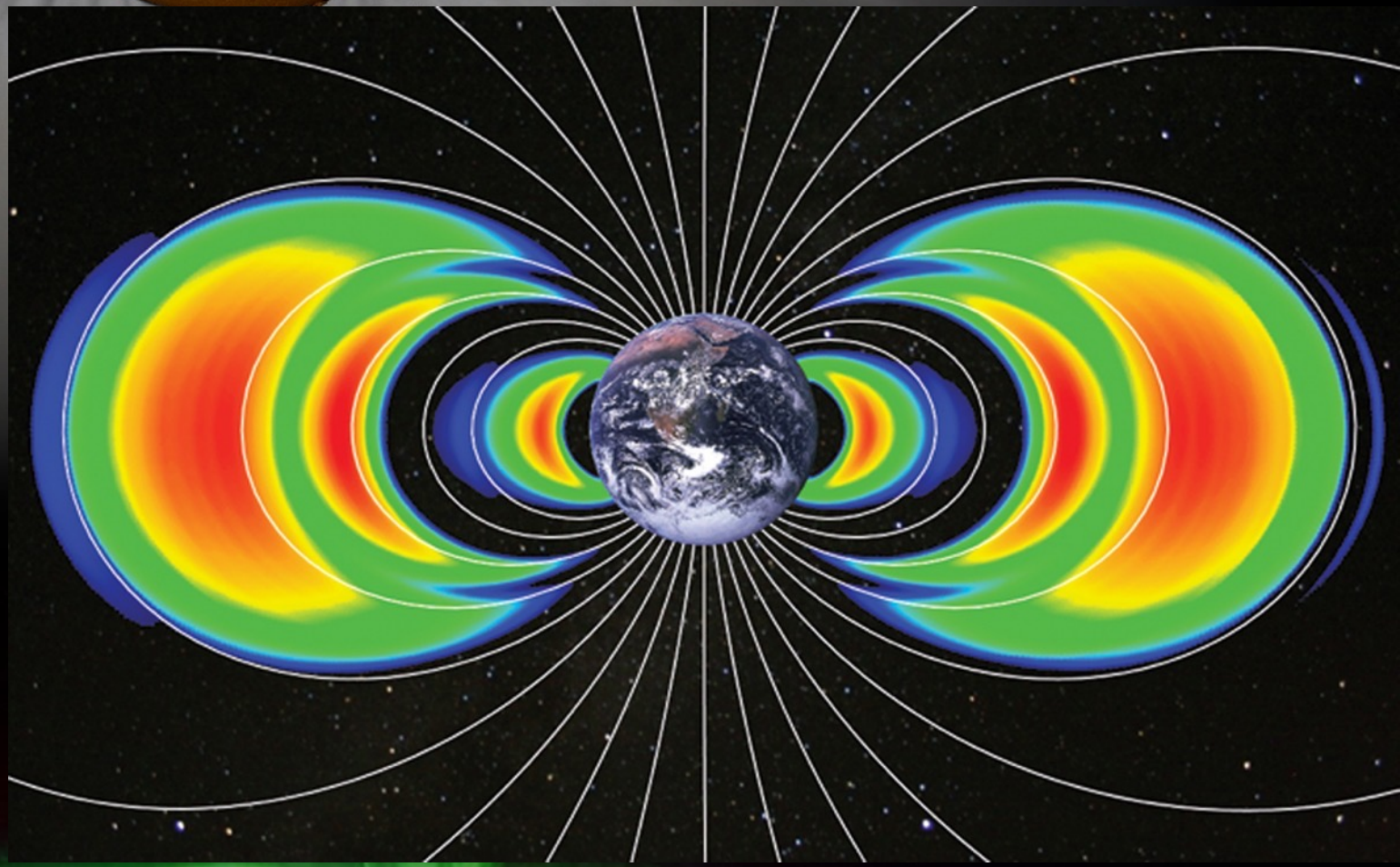
- Methods
  - E/q + dE v E’





Charge states

- Methods
  - E/q + dE v E’
  - Geomagnetic filter
    - Use Earth’s B field



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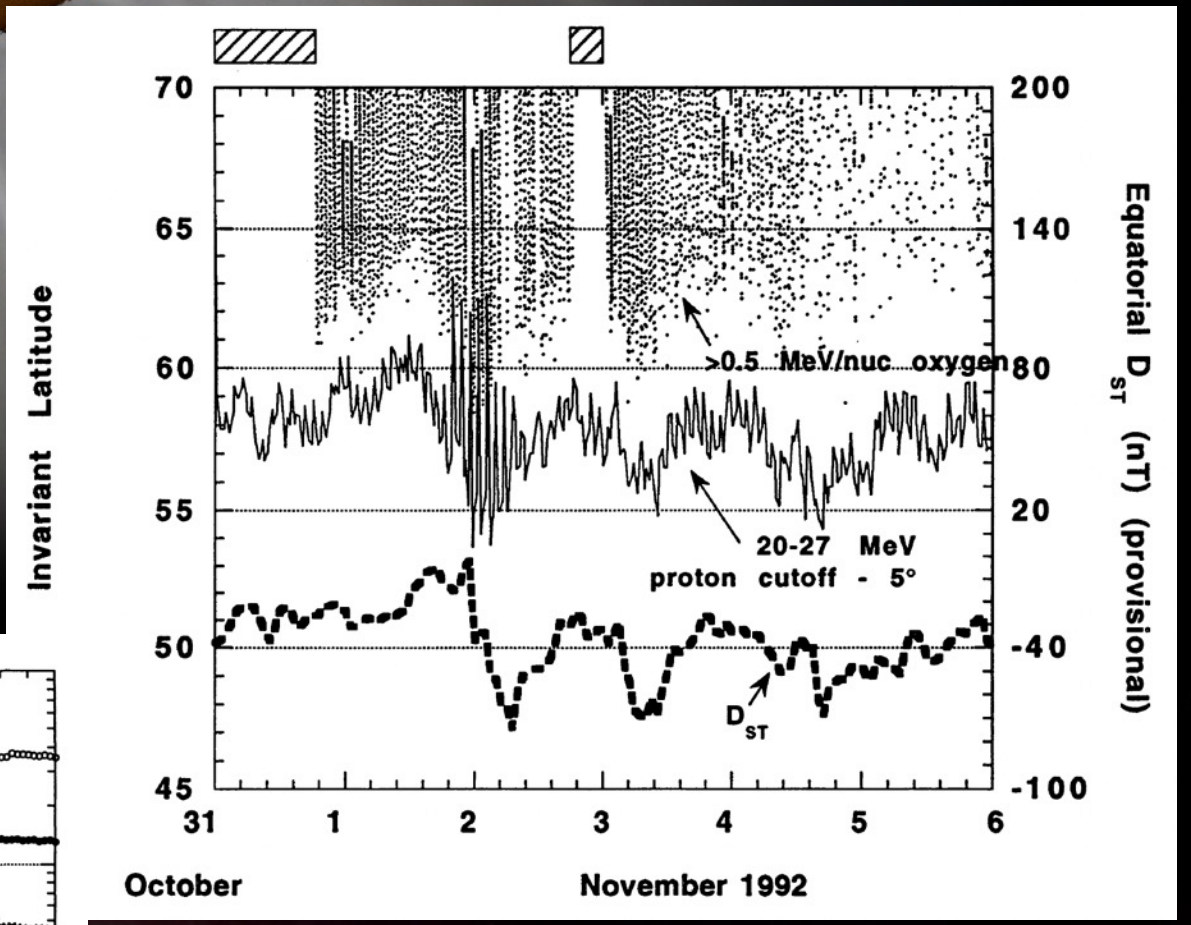
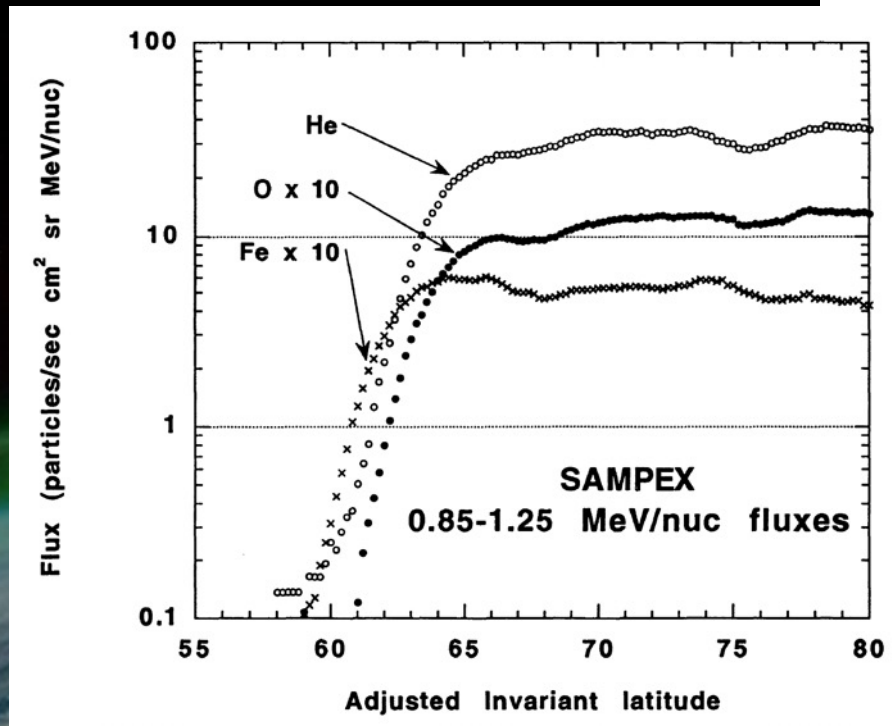
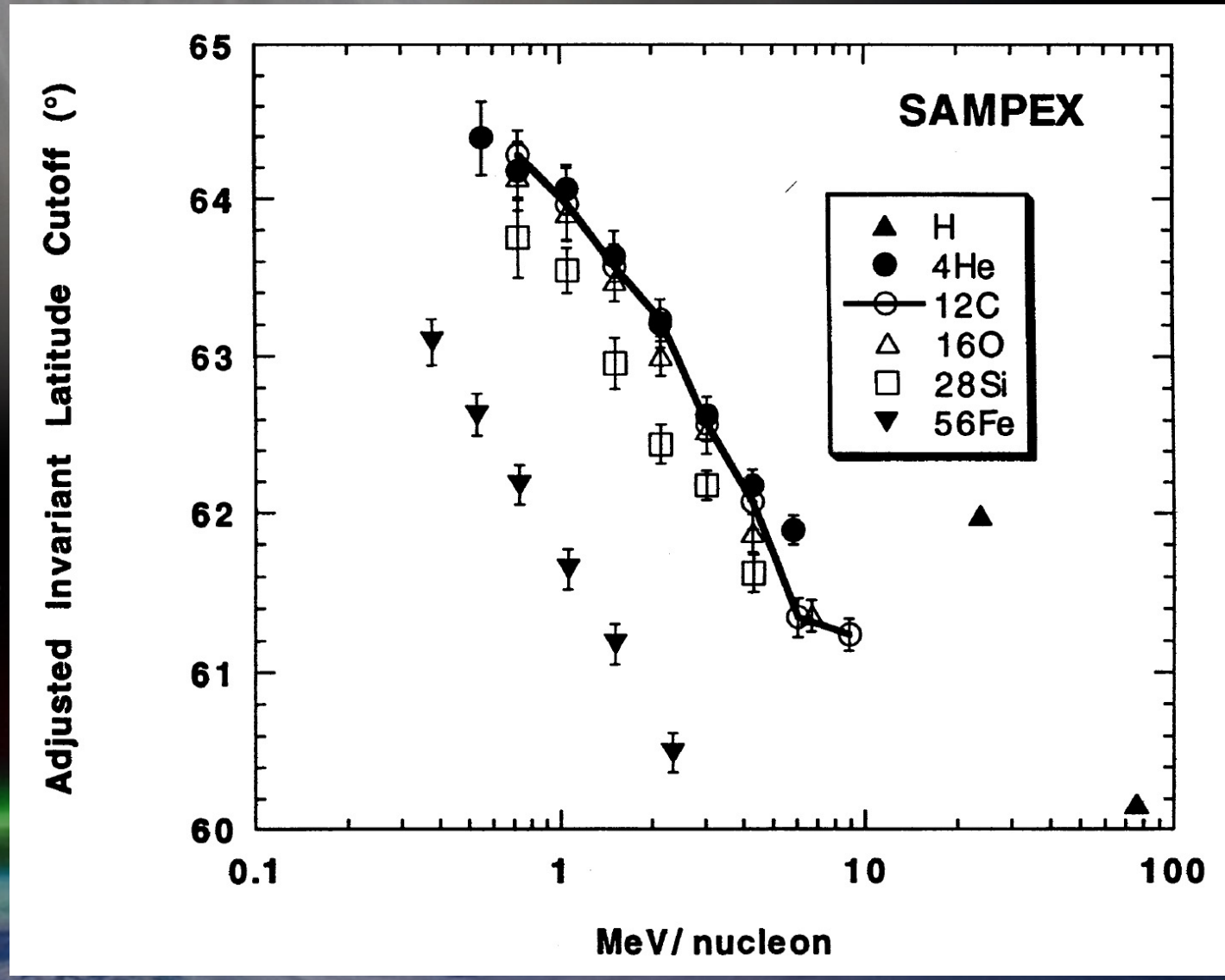




Charge states

- Methods
  - E/q + dE v E’
  - Geomagnetic filter
    - Use Earth’s B field
    - Cut off is rigidity dependent Measure M and E
    - Scale to known to get unknown q



Charge states

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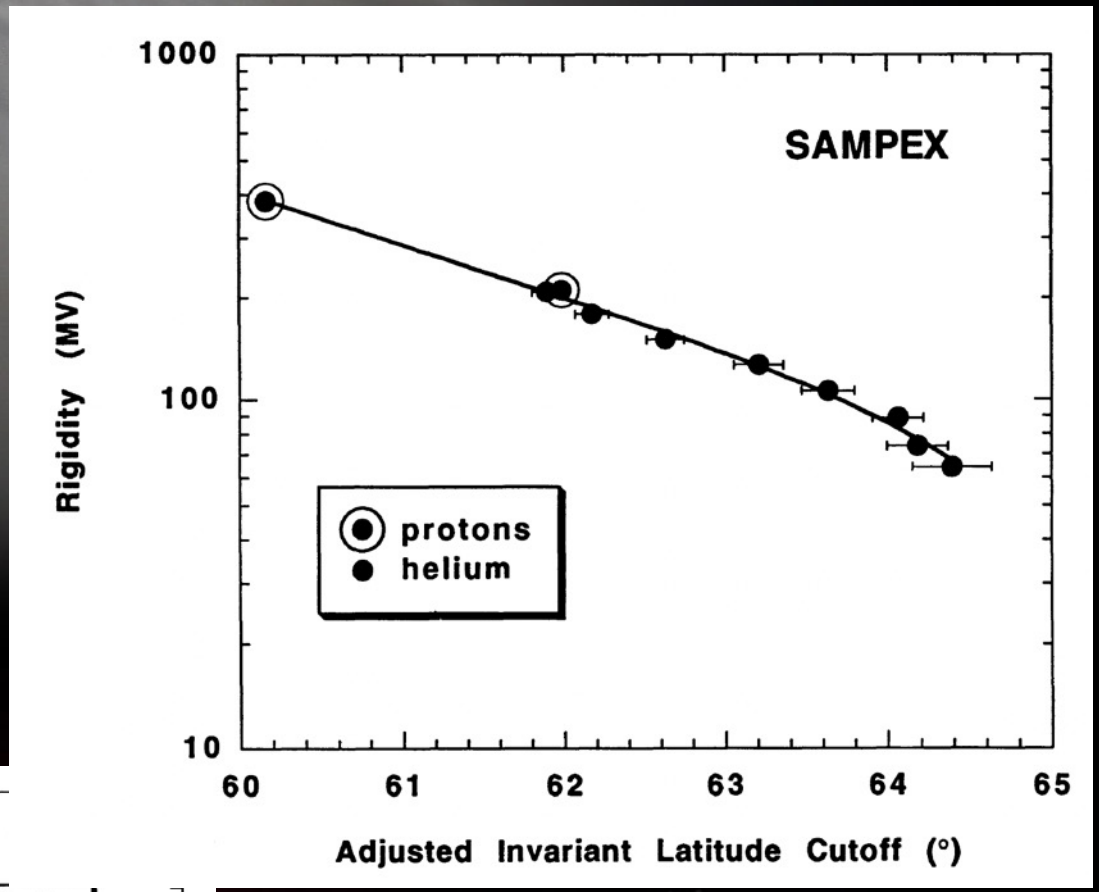
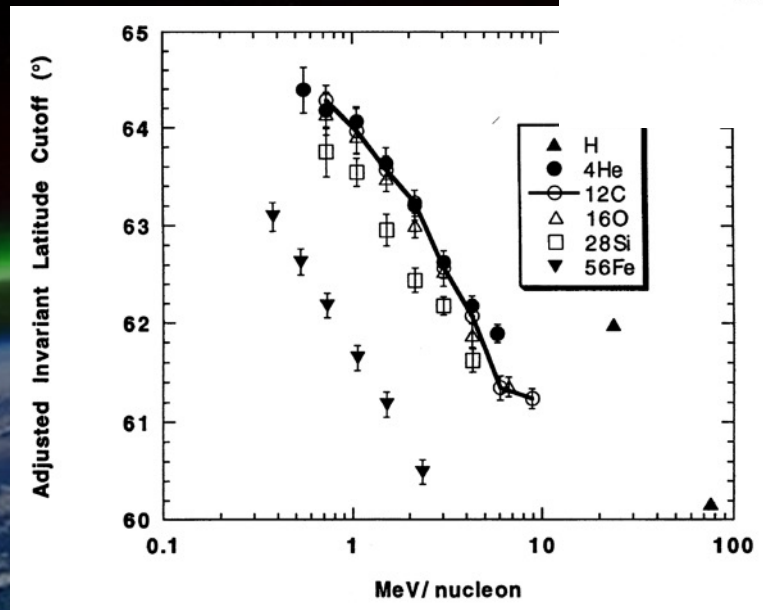




Charge states

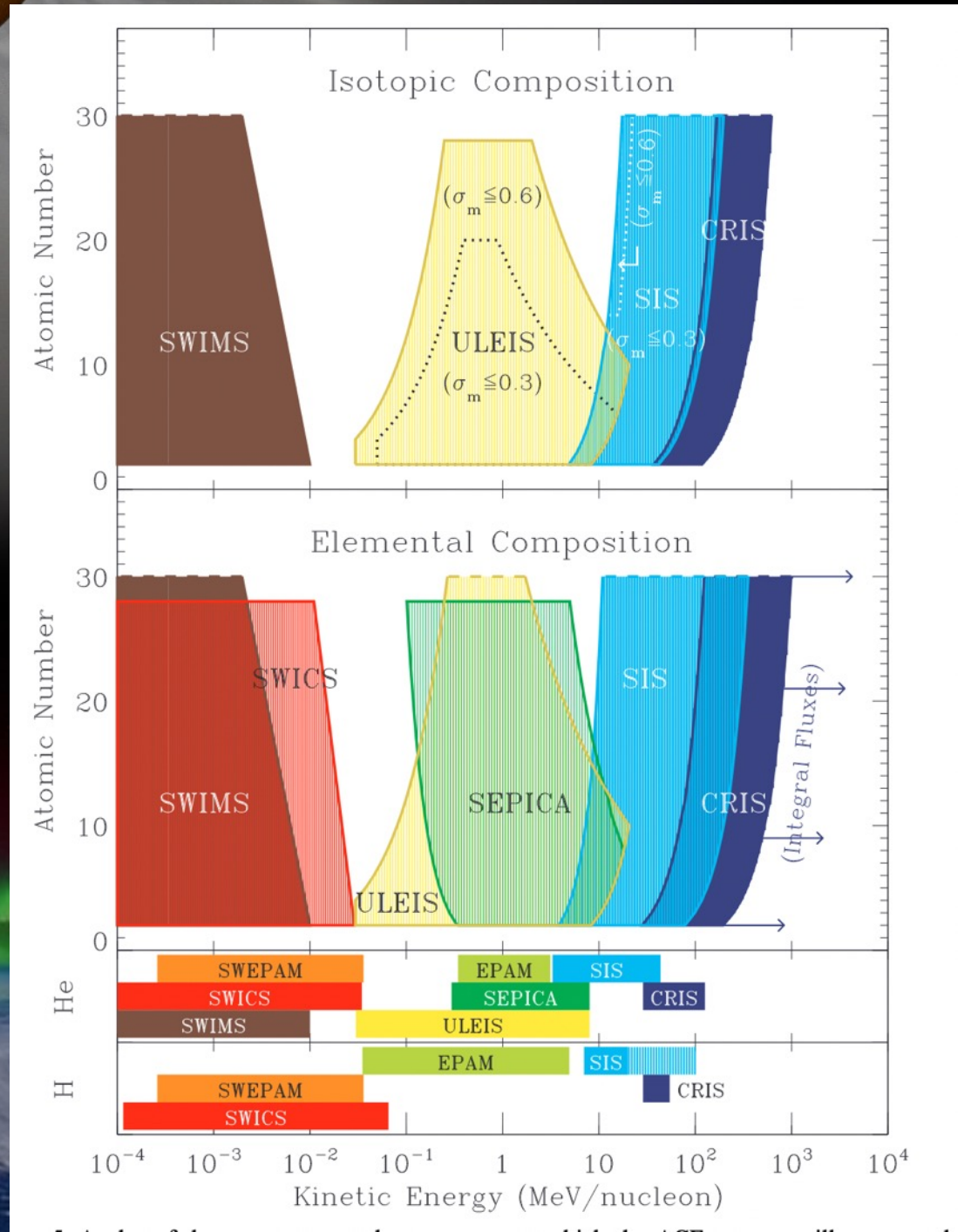
- Advantages
  - Important information
- Disadvantages
  - Limited energy range (high or low)
  - Somewhat fragile for low E
  - Requires correct orbit for high E

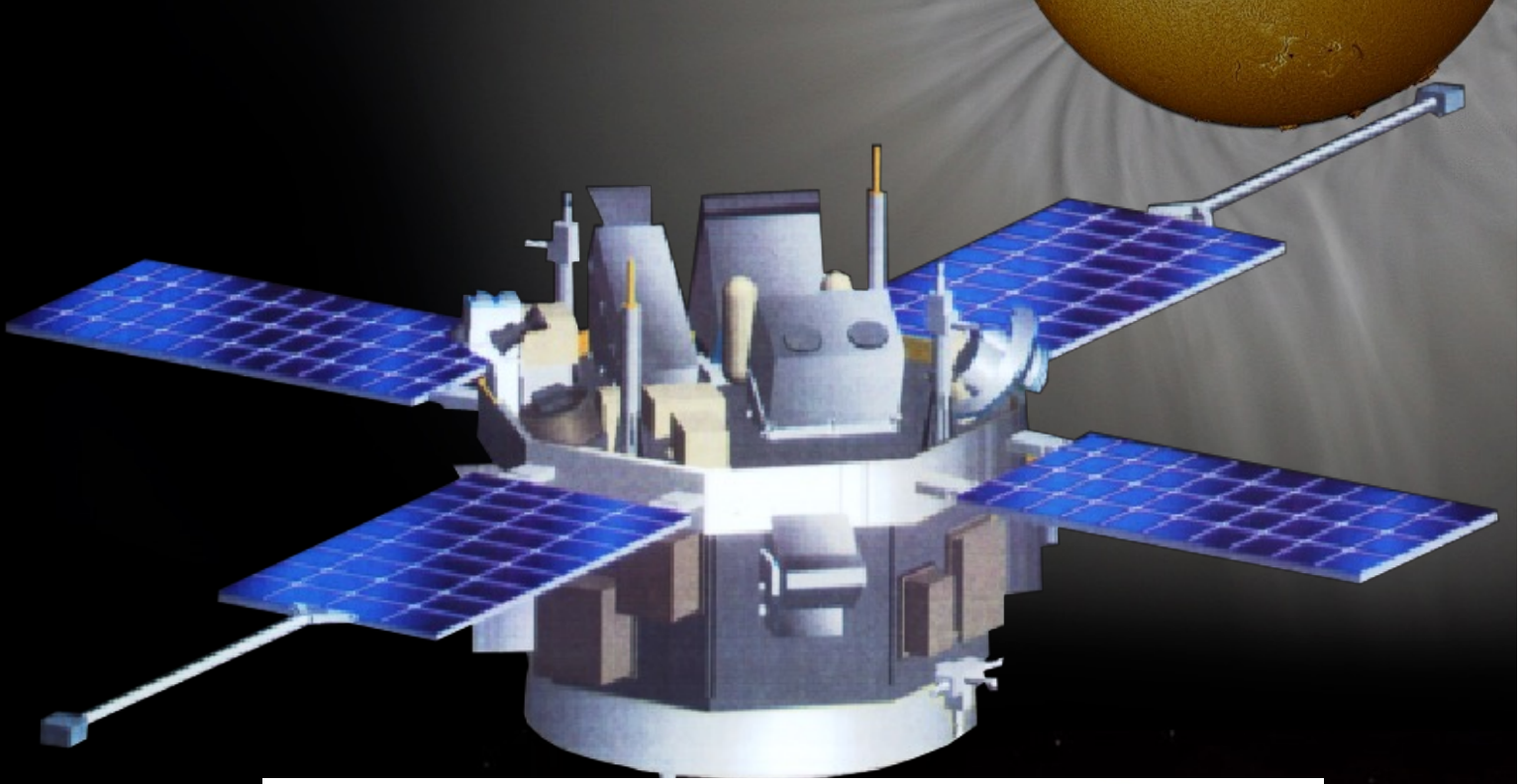
Spacecraft examples

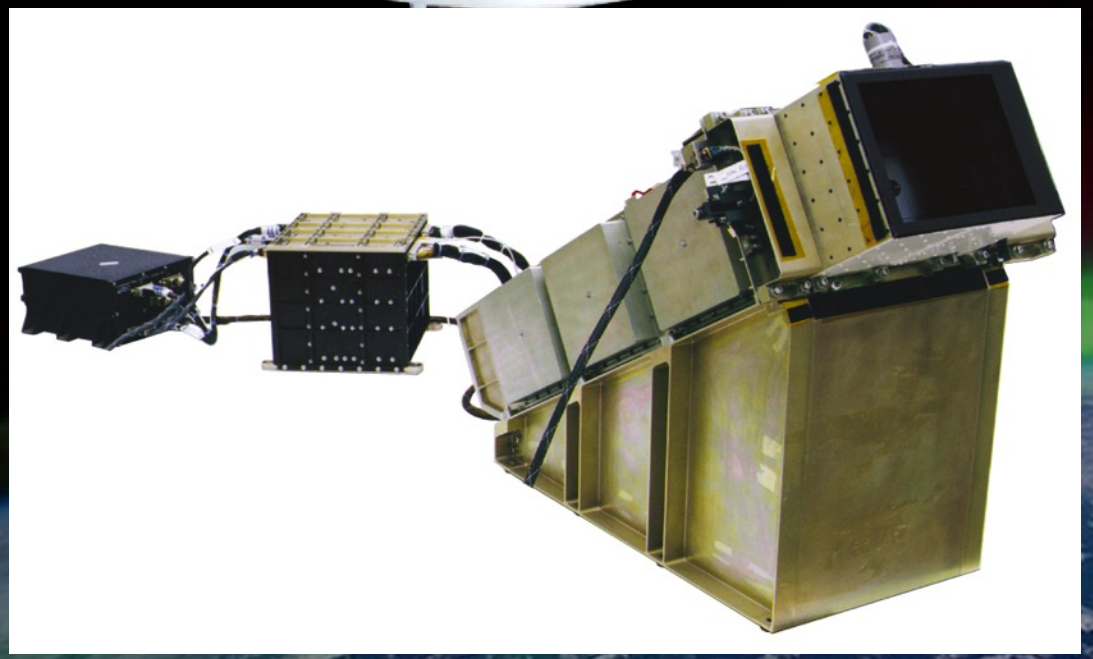
- Different trade-offs, different situations
- Advanced Composition Explorer (ACE)
  - Launched 1997
  - Spinner at L1
- Solar Terrestrial Relations Observatory (STEREO)
  - Launched 2006
  - Non-spinners, twin spacecraft drifting relative to Earth at 1 AU
- Parker Solar Probe (PSP)
  - Launched 2018
  - Elliptical orbit, perihelion very close to Sun (<10 R_S)
- Solar Orbiter (SolO)
  - Launched 2020
  - Reaches 0.3 au and out of ecliptic by 24°

ACE

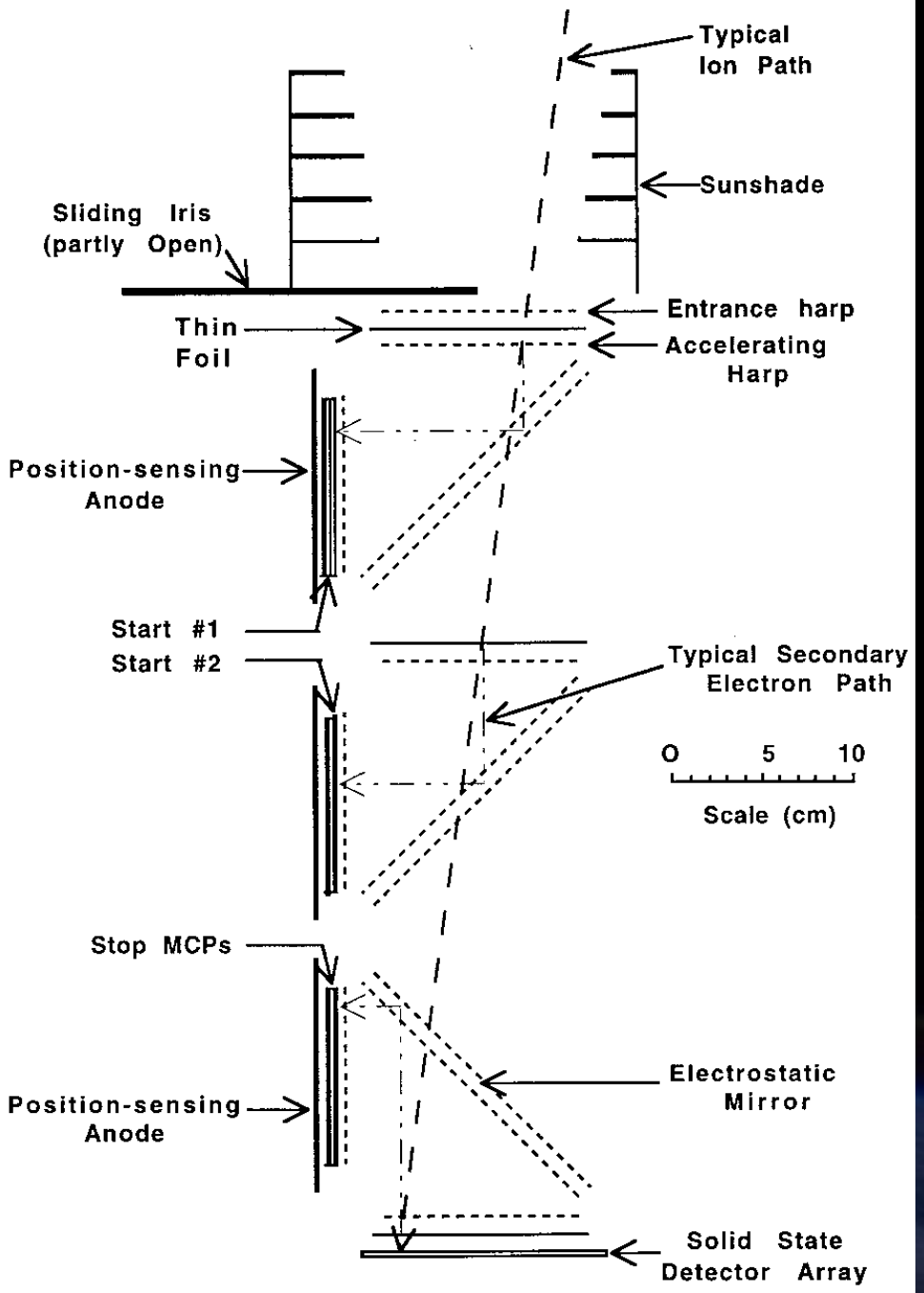
- Electron, proton and alpha monitor (EPAM)
- Solar energetic particle ionic charge analyzer (SEPICA)
- Ultra-low-energy isotope spectrometer (ULEIS)
- Solar isotope spectrometer (SIS)

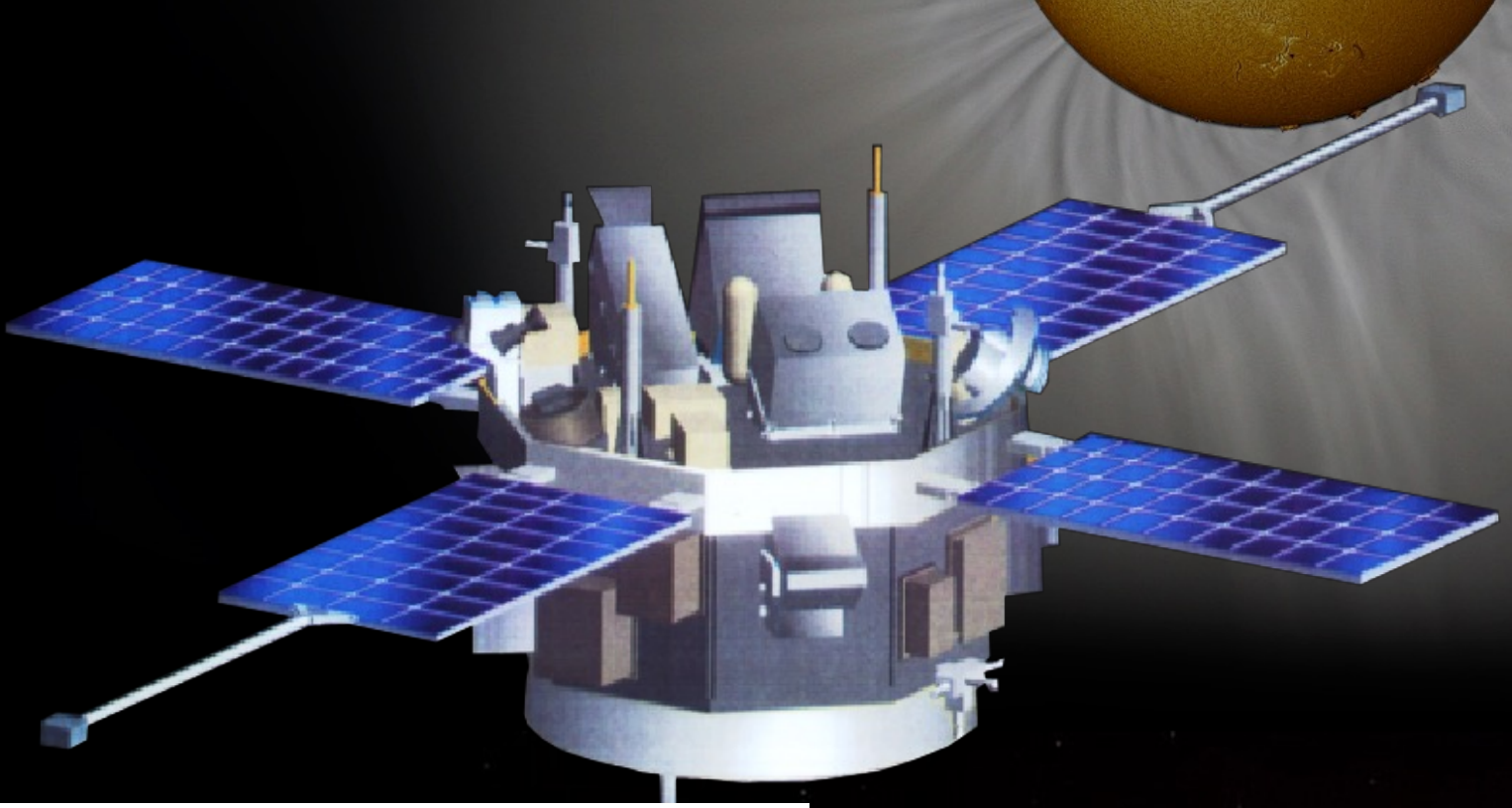


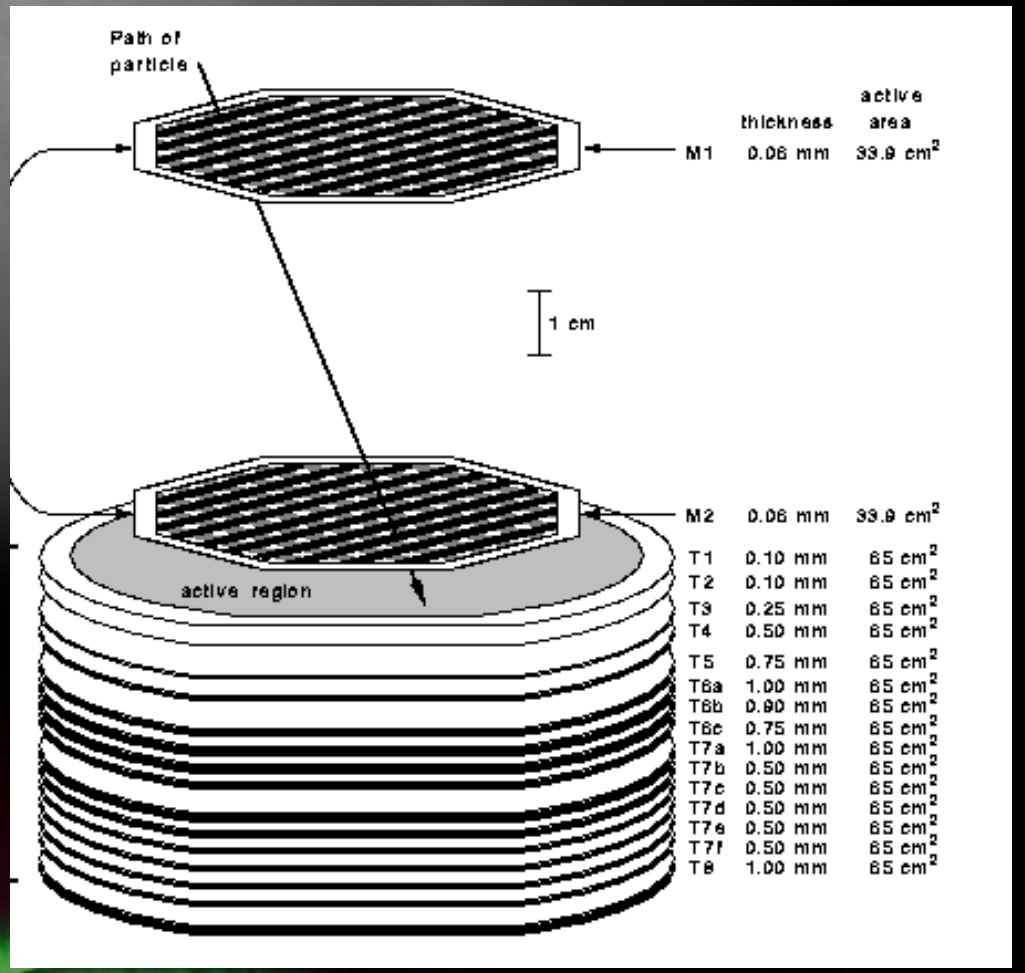




ULEIS Telescope Cross Section



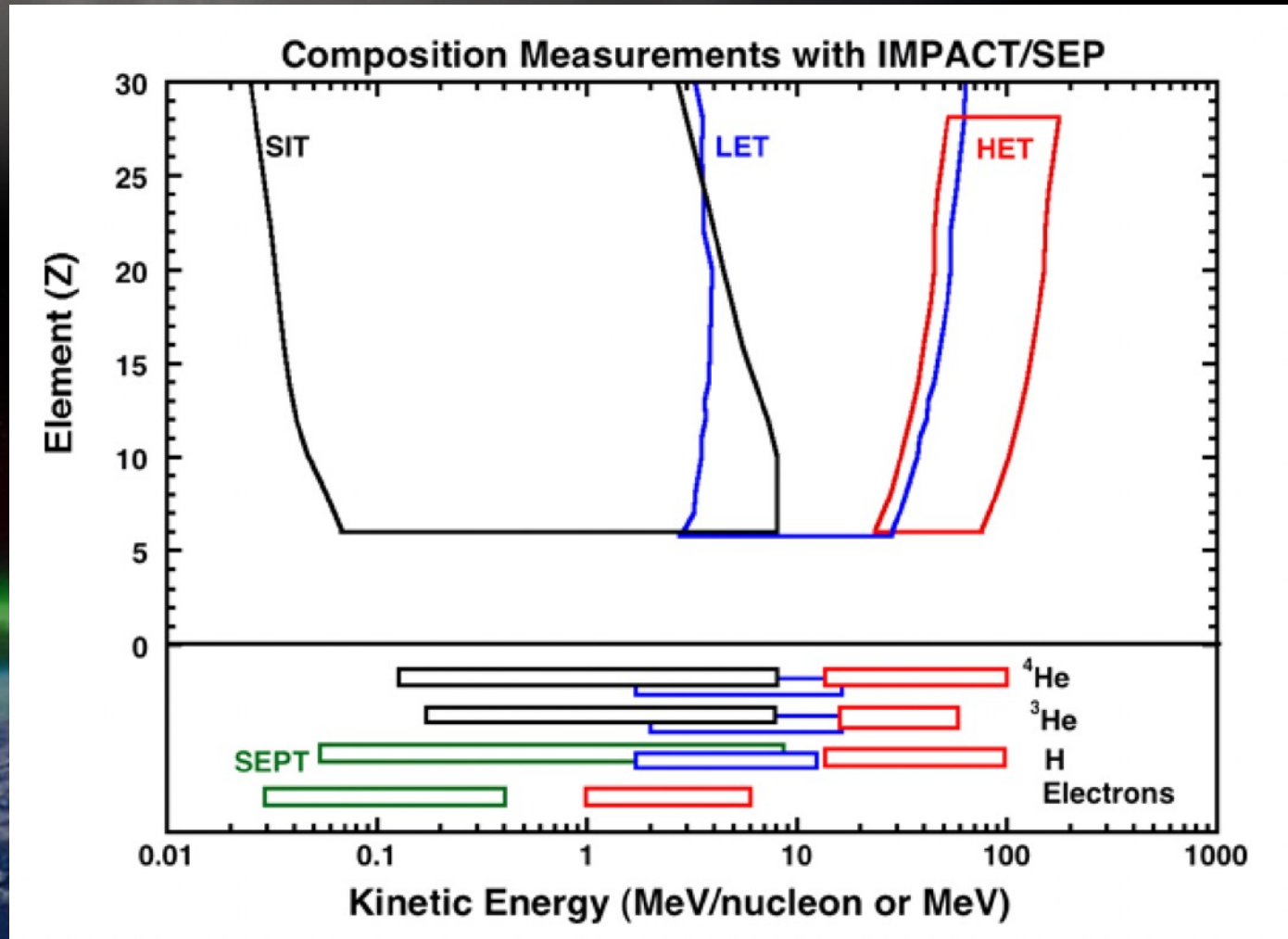


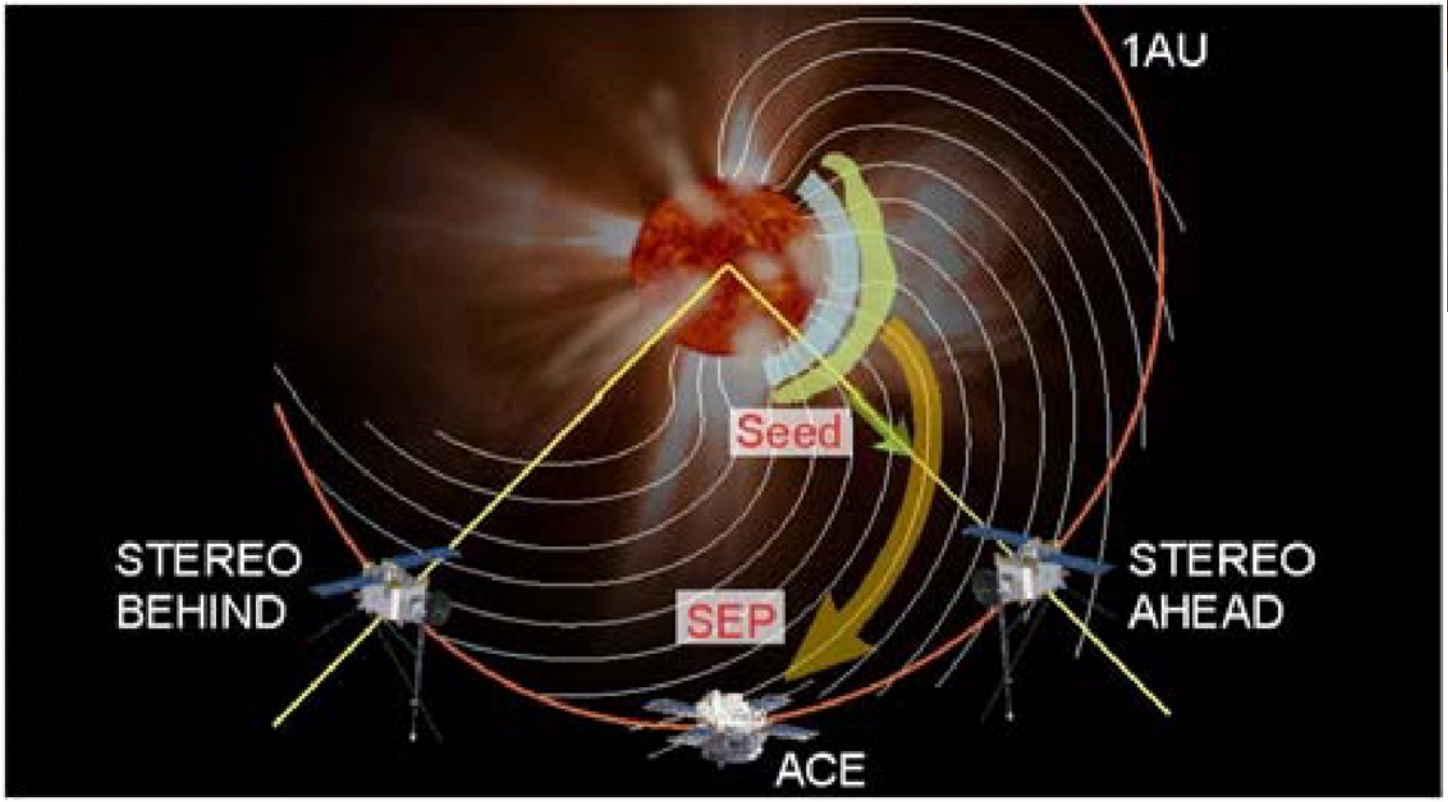

Path of particle
active
thickness area
M1 0.06 mm 33.9 cm²
1 cm
M2 0.06 mm 33.9 cm²
T1 0.10 mm 65 cm²
T2 0.10 mm 65 cm²
T3 0.25 mm 65 cm²
T4 0.50 mm 65 cm²
T5 0.75 mm 65 cm²
T6a 1.00 mm 65 cm²
T6b 0.90 mm 65 cm²
T6c 0.75 mm 65 cm²
T7a 1.00 mm 65 cm²
T7b 0.50 mm 65 cm²
T7c 0.50 mm 65 cm²
T7d 0.50 mm 65 cm²
T7e 0.50 mm 65 cm²
T7f 0.50 mm 65 cm²
T8 1.00 mm 65 cm²
active region

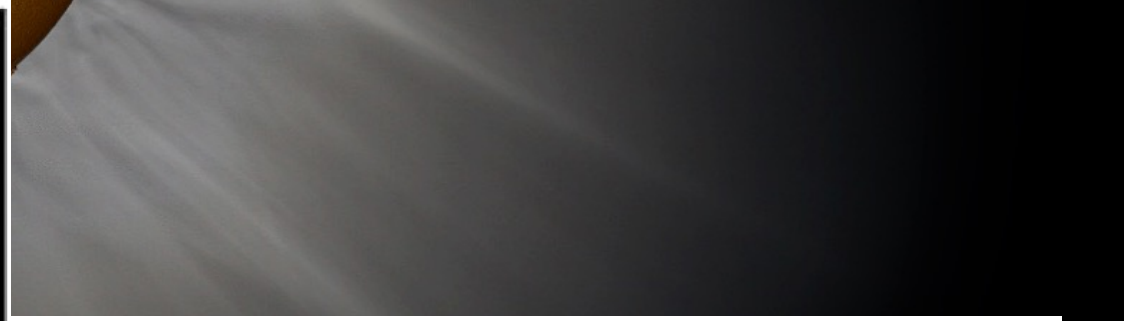
SIS

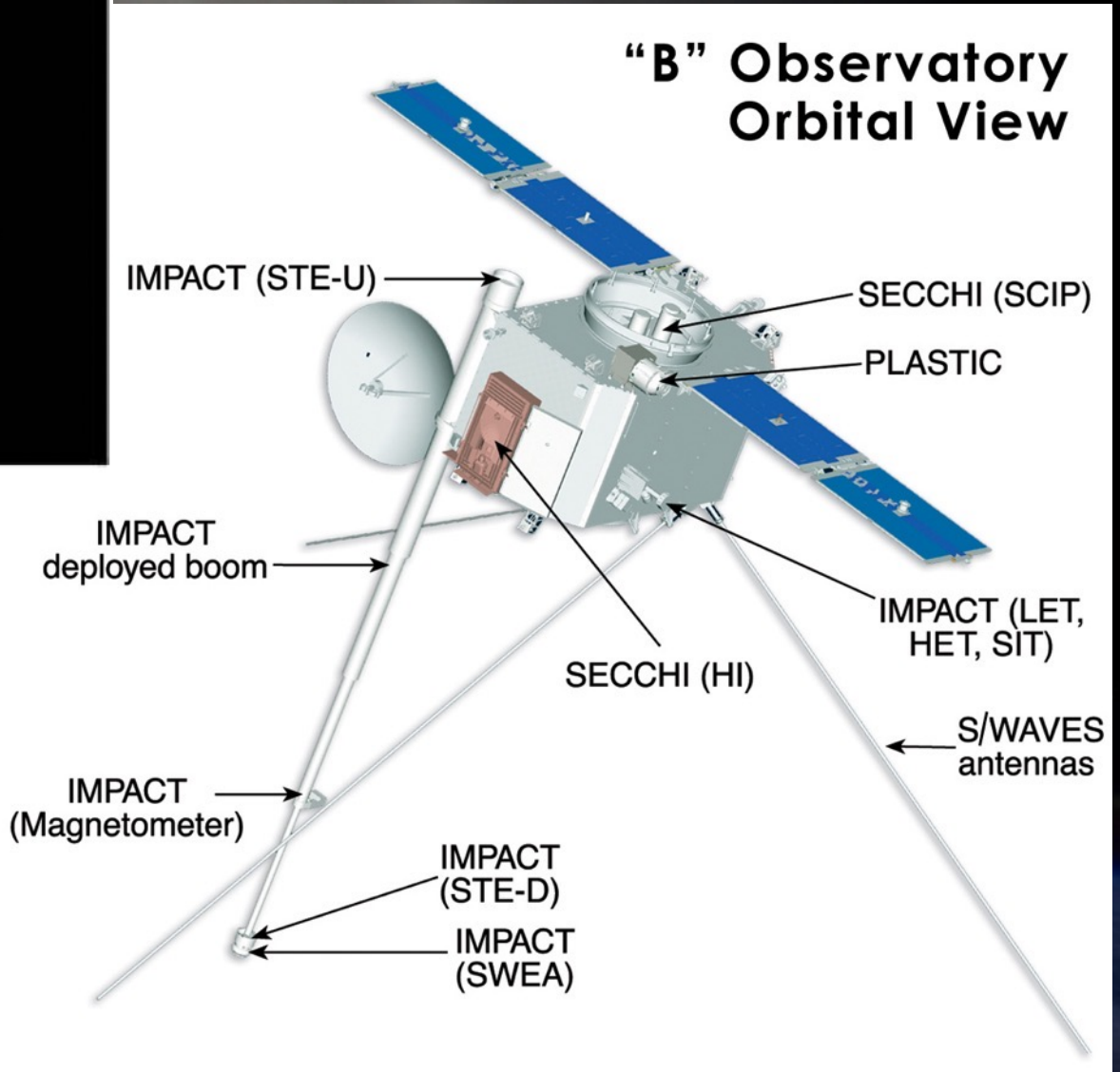
STEREO

- In situ measurements of particles and CME transients (IMPACT)
  - Solar electron and proton telescope (SEPT)
  - Suprathermal ion telescope (SIT)
  - Low energy telescope (LET)
  - High energy telescope (HET)

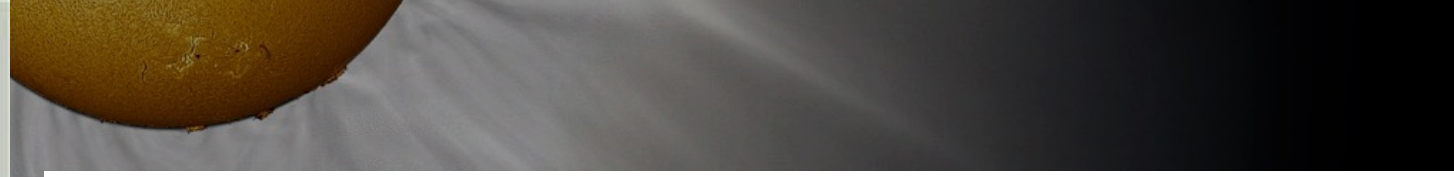


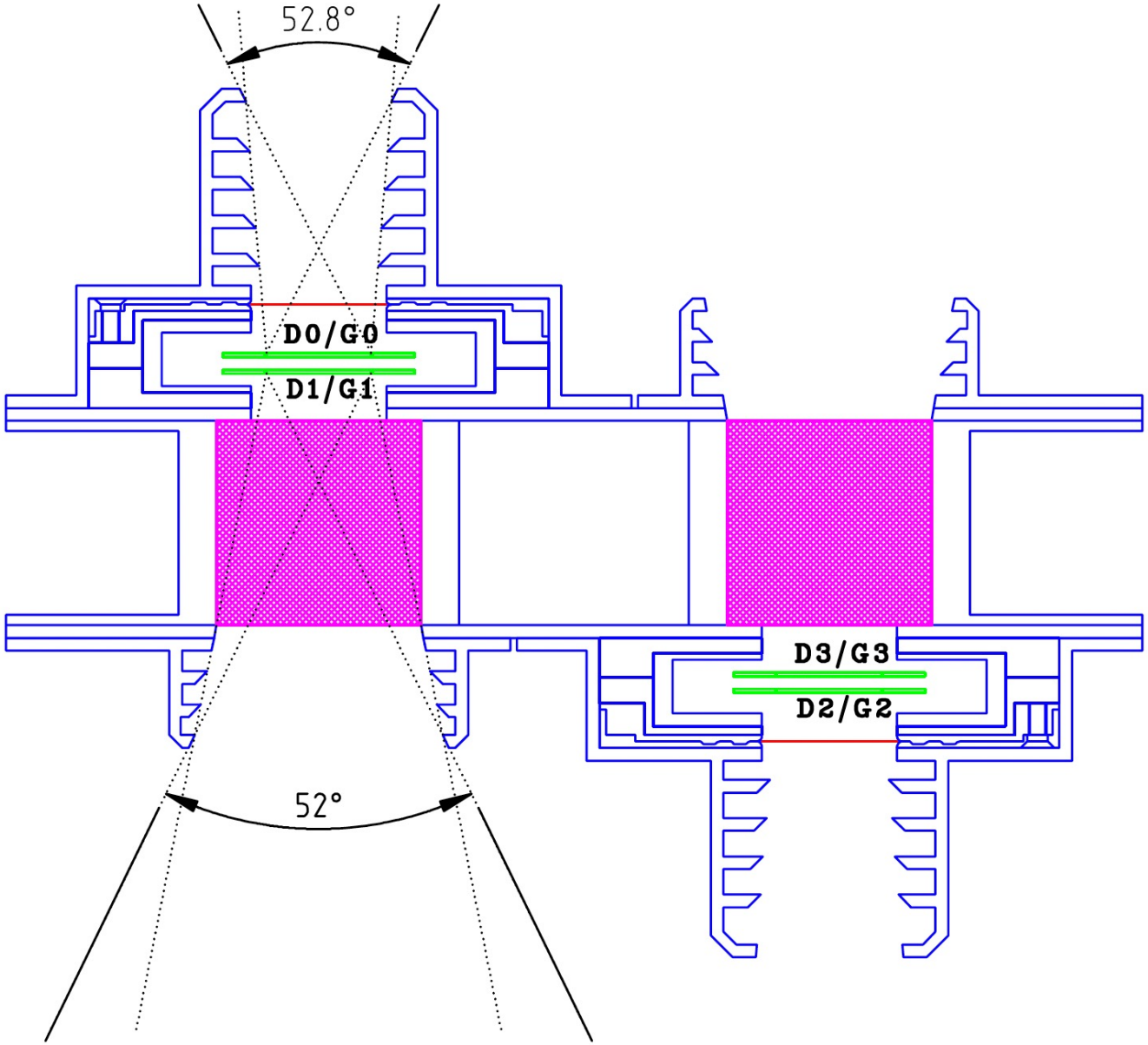

1AU
Seed
STEREO
BEHIND
SEP
STEREO
AHEAD
ACE

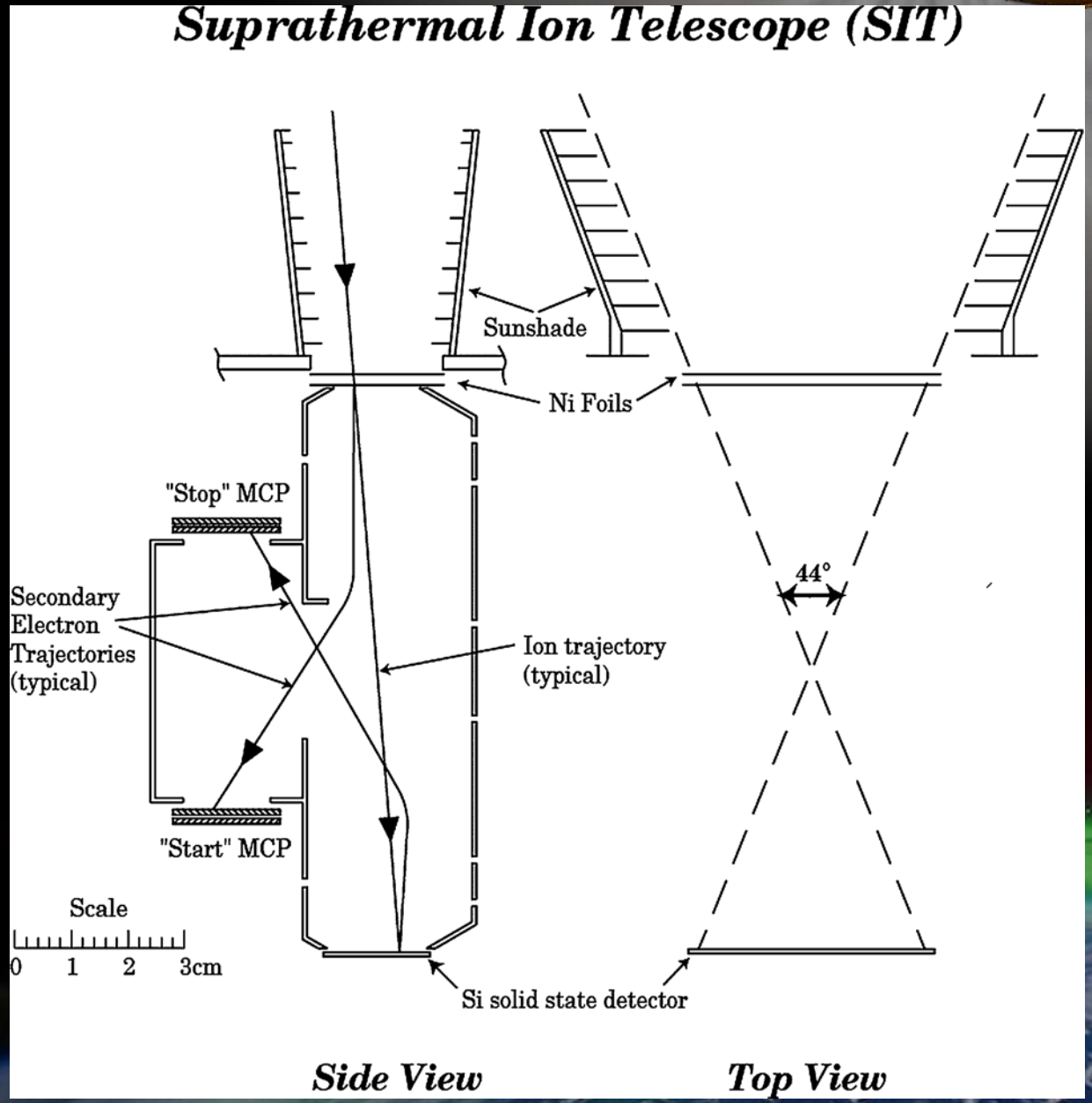


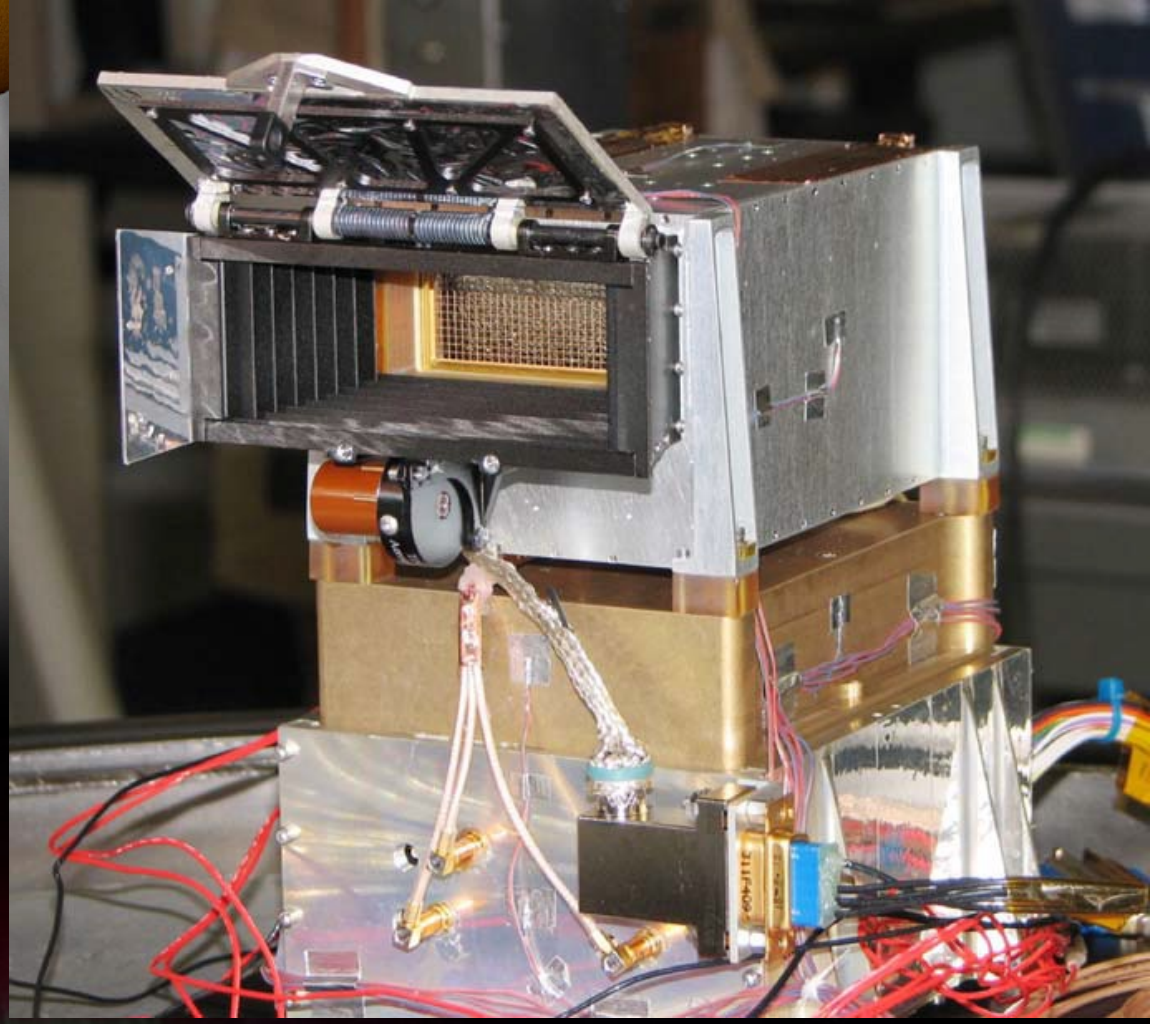

"B" Observatory
Orbital View
IMPACT (STE-U)
SECCHI (SCIP)
PLASTIC
IMPACT
deployed boom
IMPACT (LET,
HET, SIT)
SECCHI (HI)
S/WAVES
antennas
IMPACT
(Magnetometer)
IMPACT
(STE-D)
IMPACT
(SWEA)

SEPT



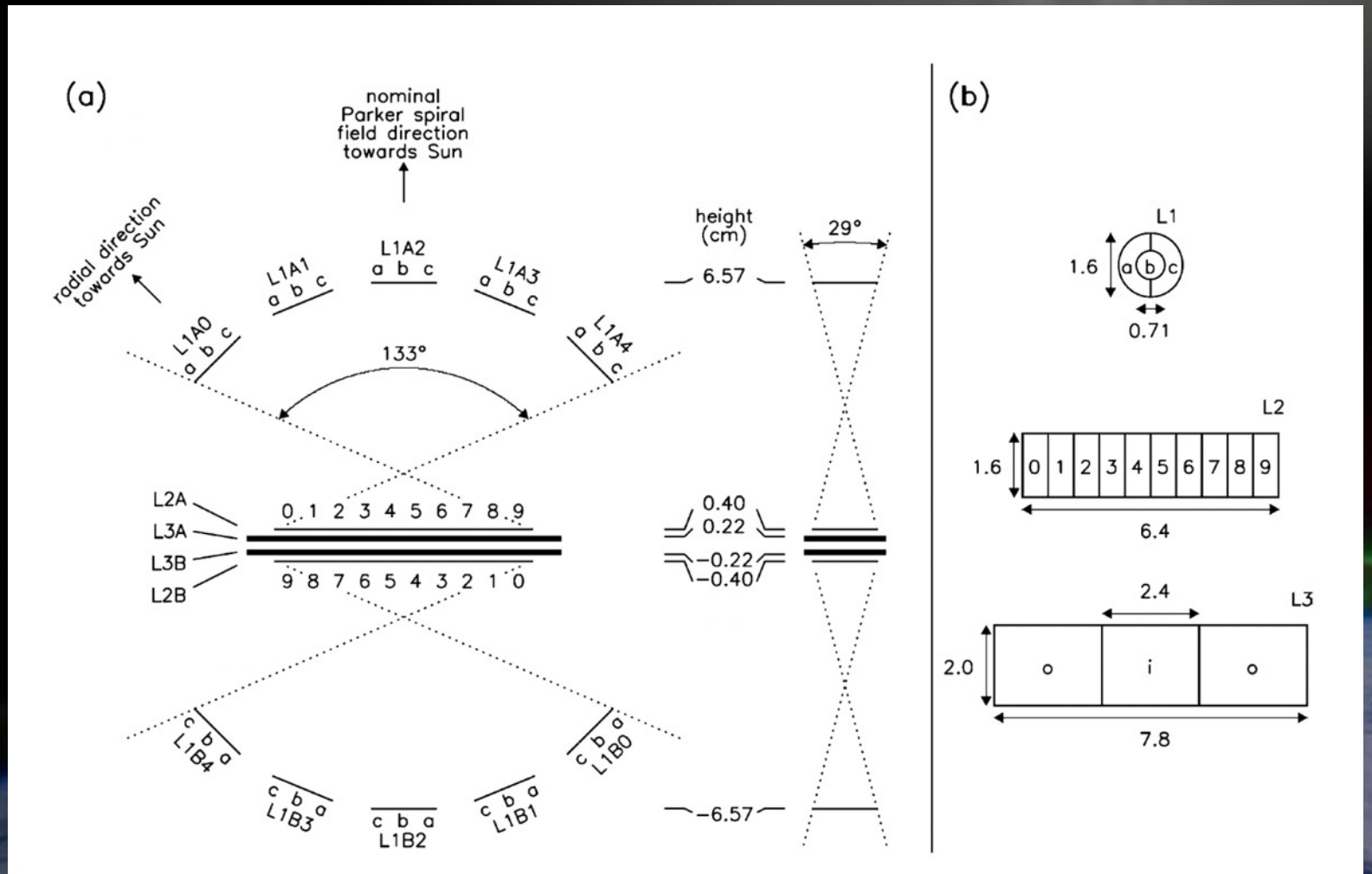



Suprathermal Ion Telescope (SIT)
Sunshade
Ni Foils
"Stop" MCP
Secondary
Electron
Trajectories
(typical)
Ion trajectory
(typical)
44°
"Start" MCP
Scale
0 1 2 3cm
Si solid state detector
Side View
Top View



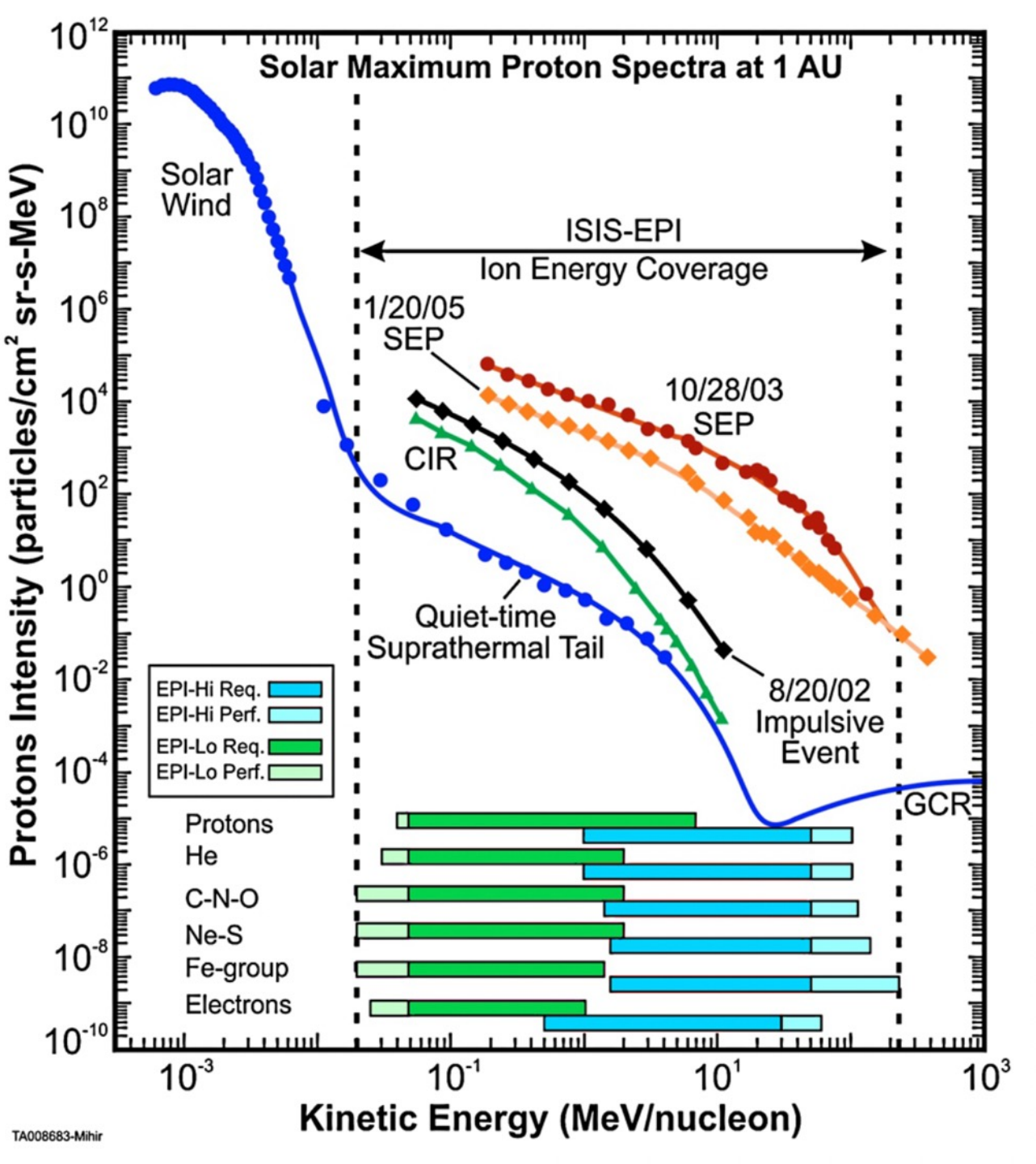
SIT

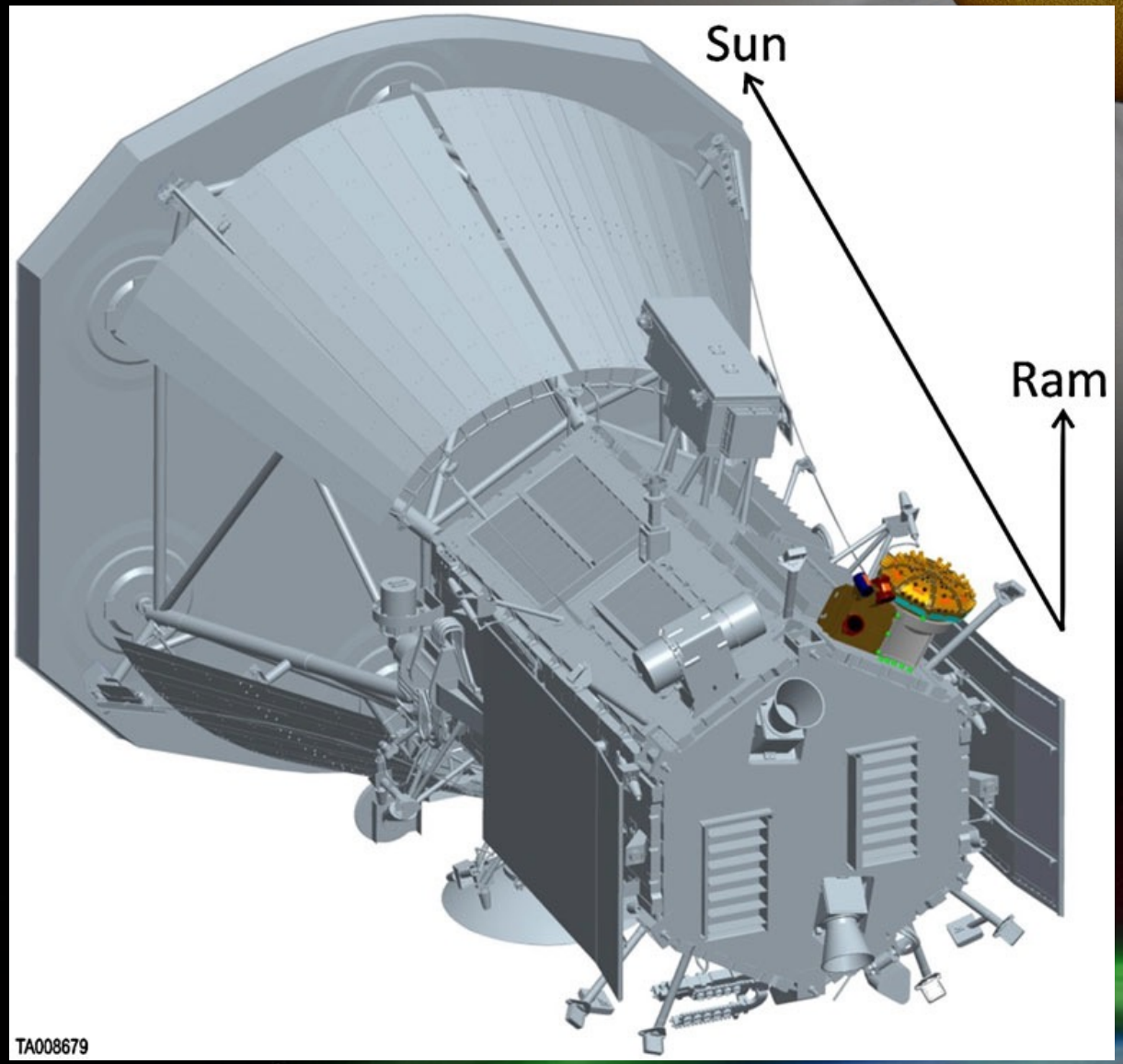
LET & HET

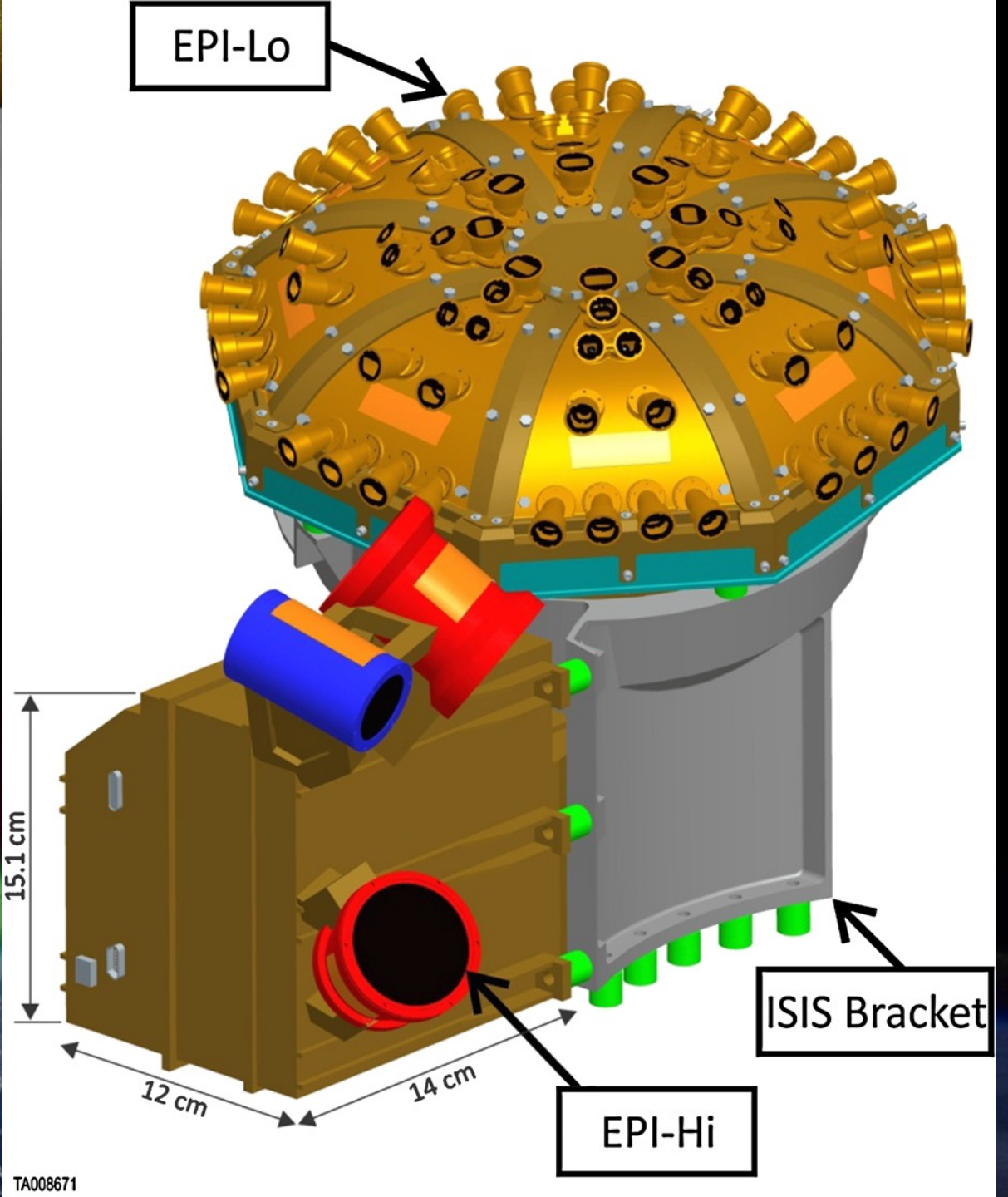

(a)
nominal
Parker spiral
field direction
towards Sun
radial direction
towards Sun
L1A0
L1A1
L1A2
L1A3
L1A4
a b c
133°
height
(cm)
29°
6.57
L2A
L3A
L3B
L2B
0 1 2 3 4 5 6 7 8 9
9 8 7 6 5 4 3 2 1 0
0.40
0.22
−0.22
−0.40
L1B4
L1B3
L1B2
L1B1
L1B0
c b a
−6.57
(b)
L1
1.6
0.71
L2
6.4
2.4
L3
2.0
o
i
7.8

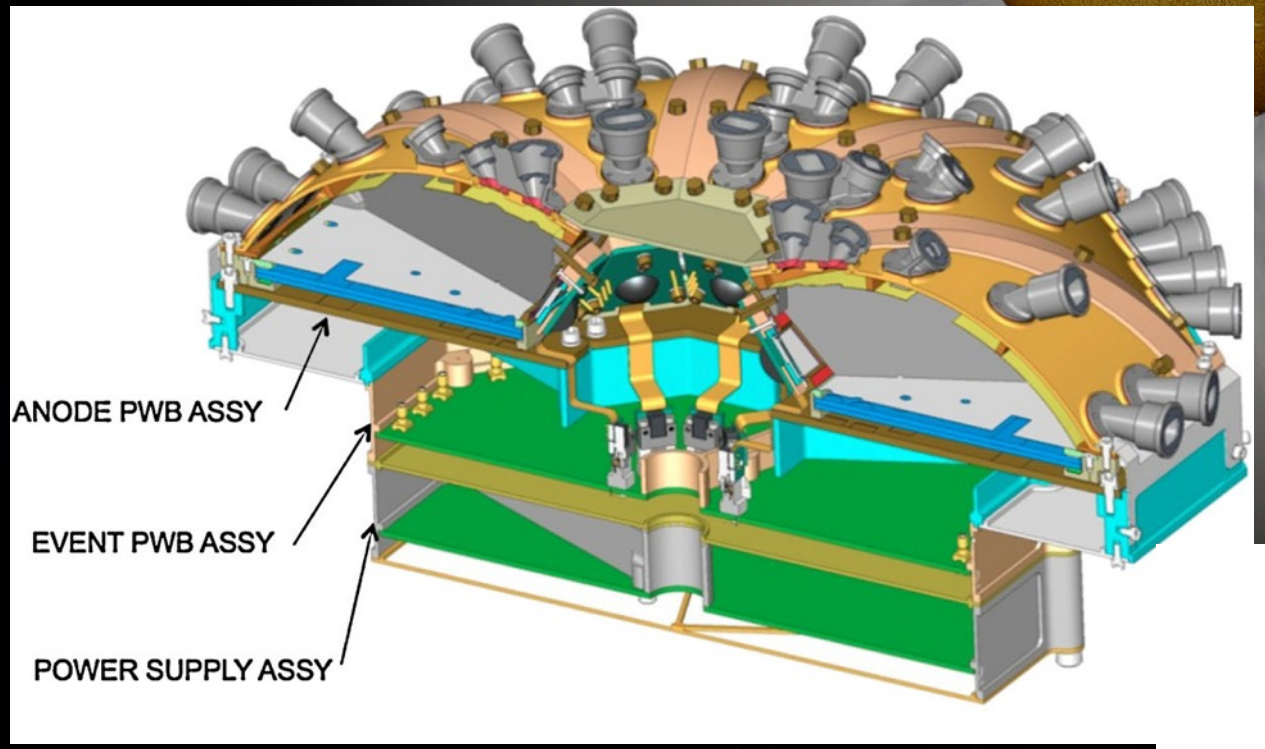
PSP

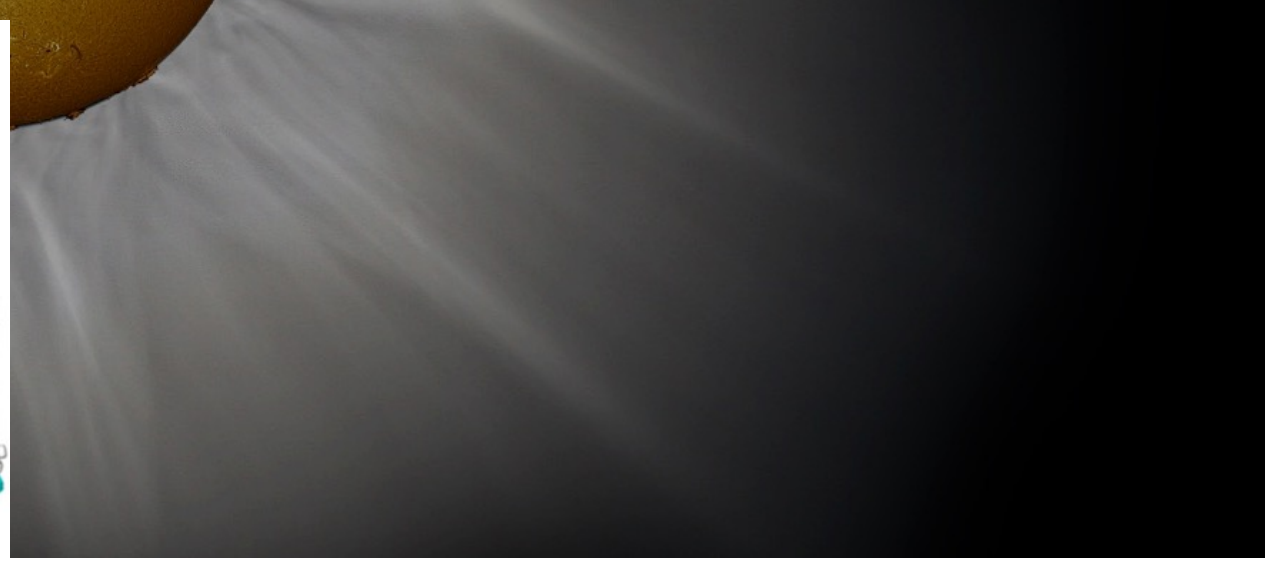
- Integrated science investigation of the Sun (ISOIS)
  - Energetic particle instrument – Lo (EPI-Lo)
  - Energetic particle instrument – Hi (EPI-Hi; LET, HET)

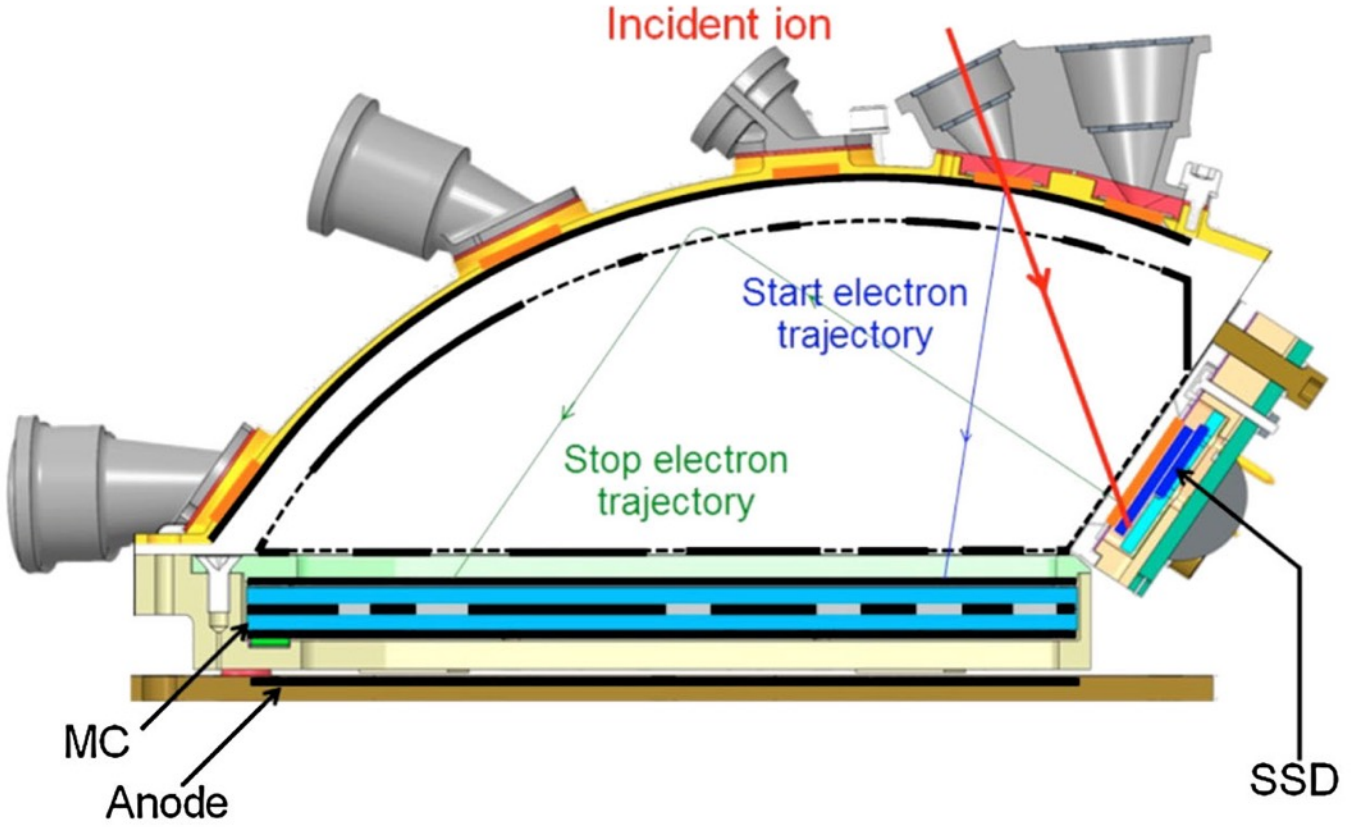


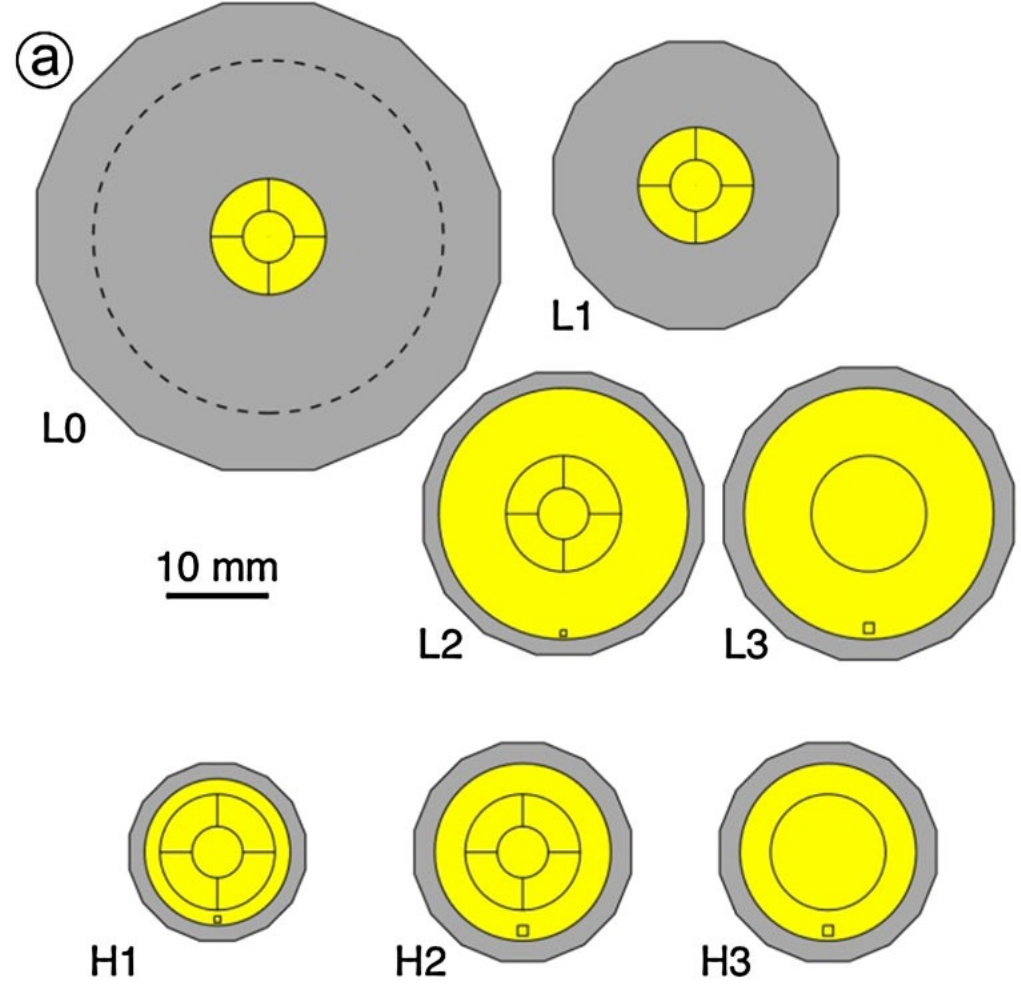

Sun
Ram
TA008679

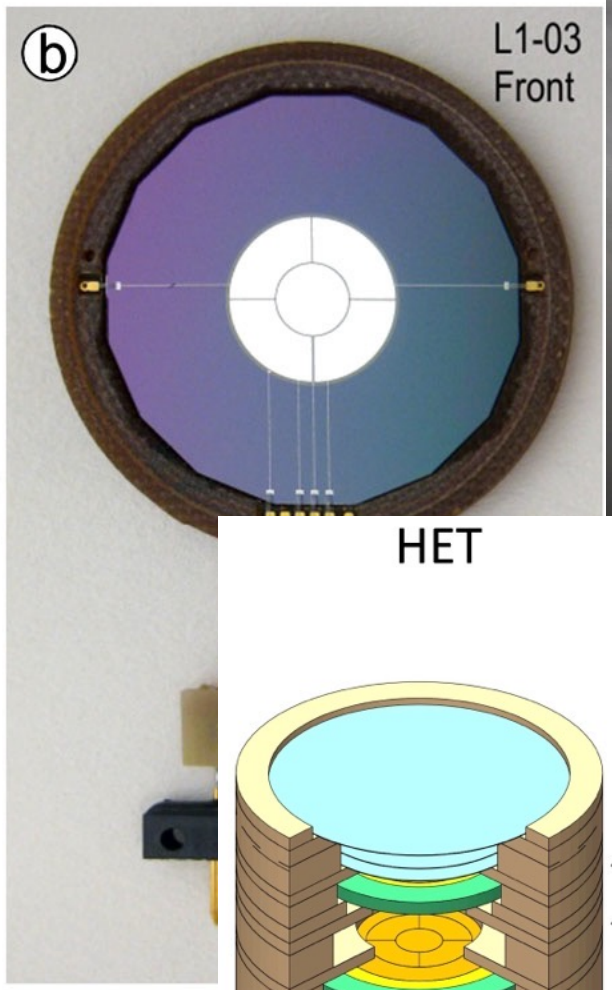

EPI-Lo
15.1 cm
12 cm
14 cm
ISIS Bracket
EPI-Hi
TA008671

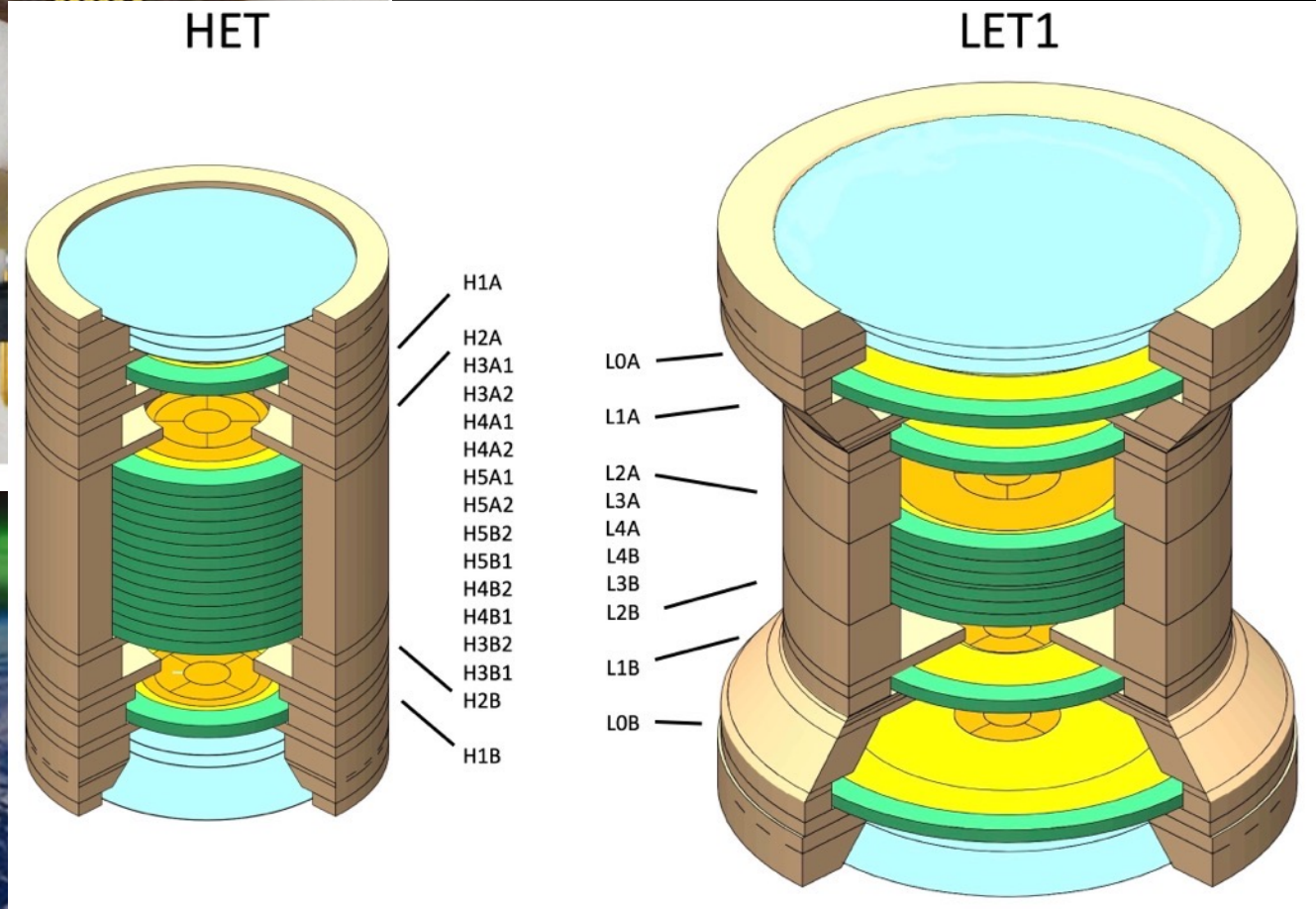

ANODE PWB ASSY
EVENT PWB ASSY
POWER SUPPLY ASSY




Incident ion
Start electron trajectory
Stop electron trajectory
MC
Anode
SSD
TA008681


a
L0
L1
L2
L3
10 mm
H1
H2
H3

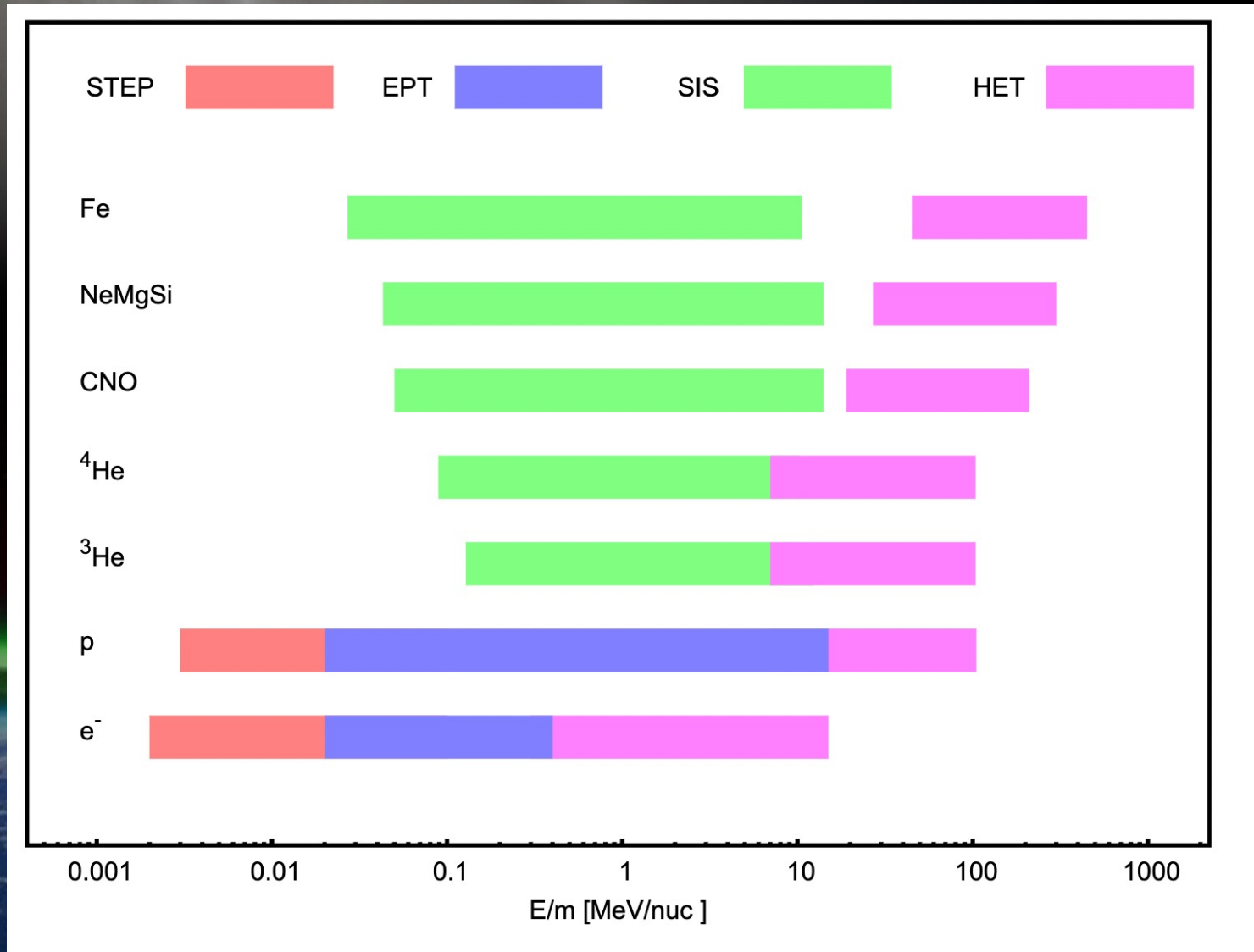

b
L1-03
Front

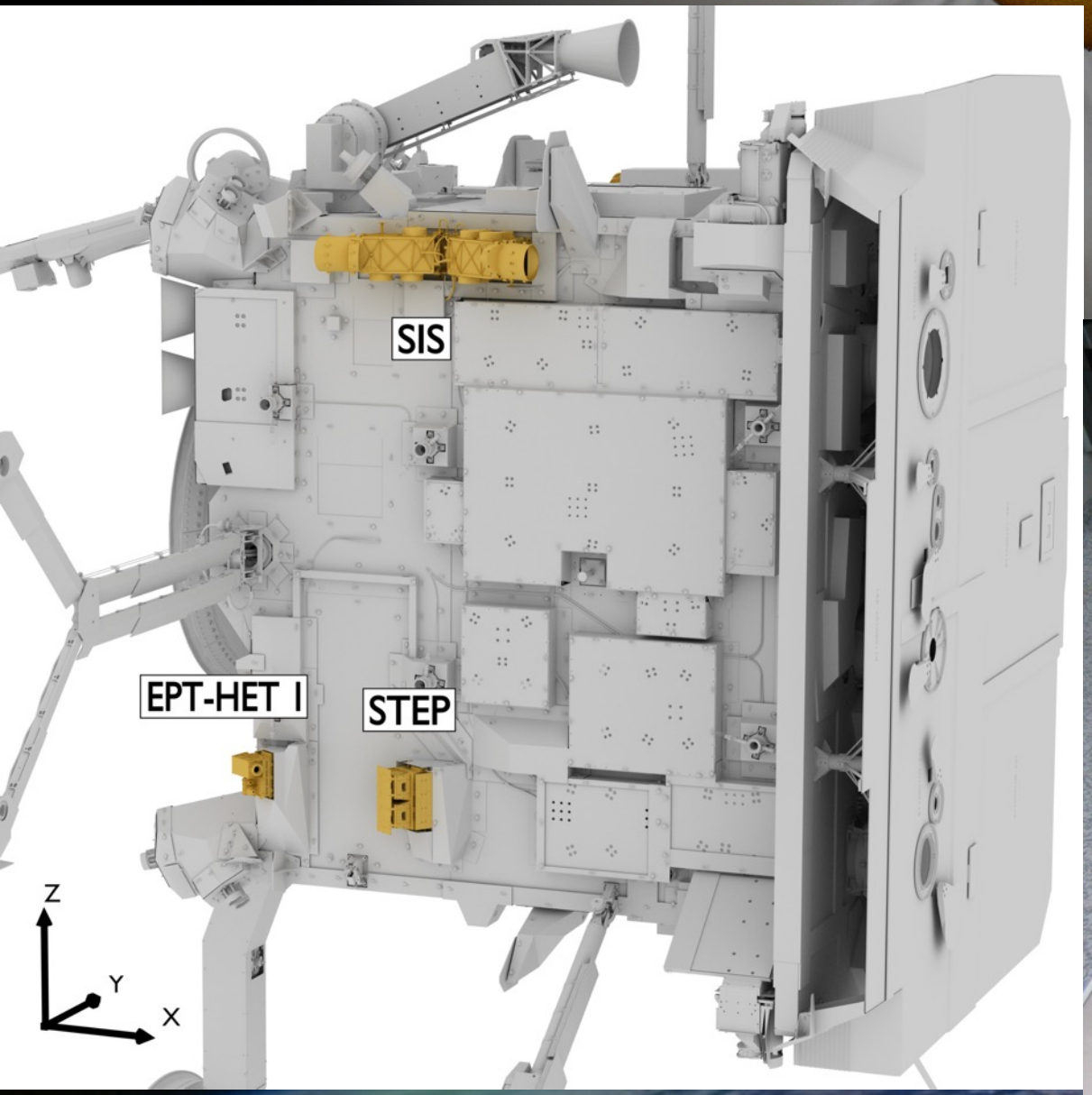

HET
H1A
H2A
H3A1
H3A2
H4A1
H4A2
H5A1
H5A2
H5B2
H5B1
H4B2
H4B1
H3B2
H3B1
H2B
H1B
LET1
L0A
L1A
L2A
L3A
L4A
L4B
L3B
L2B
L1B
L0B

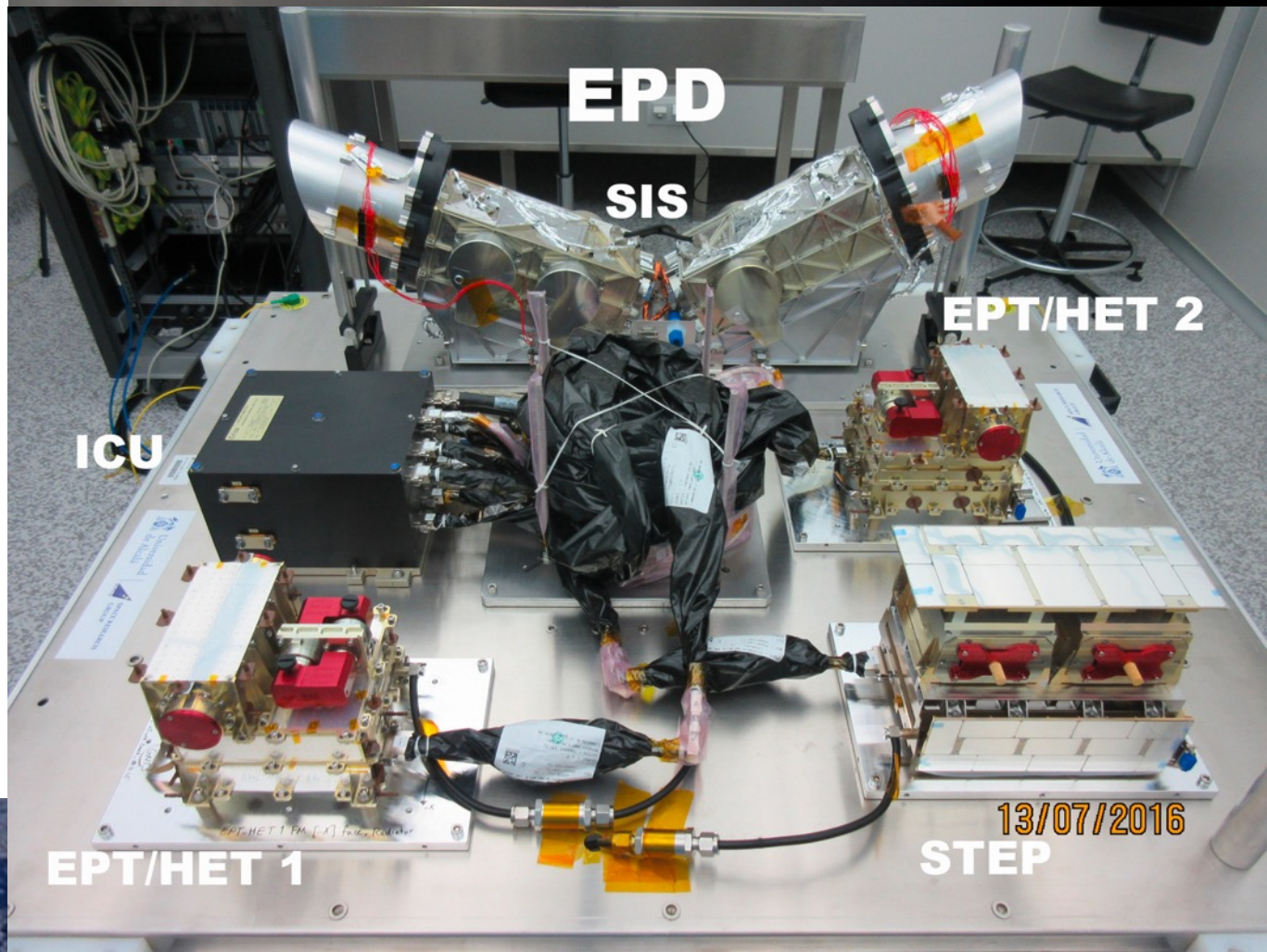
TA008652

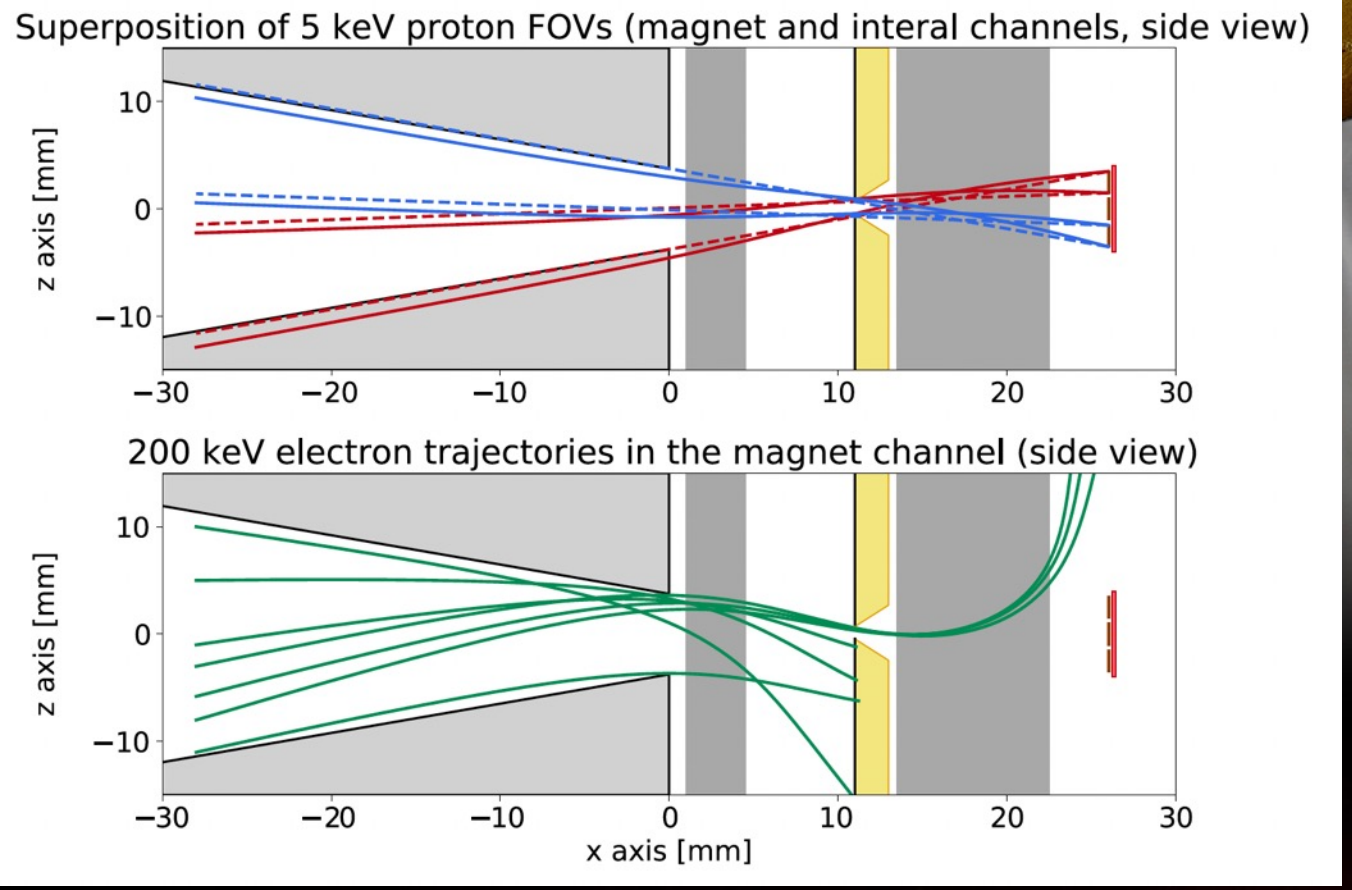
SolO

- Energetic particle detector (EPD)
  - Suprathermal electrons and protons (STEP)
  - Electron proton telescope (EPT)
  - Suprathermal ion spectrograph (SIS)
  - High energy telescope (HET)

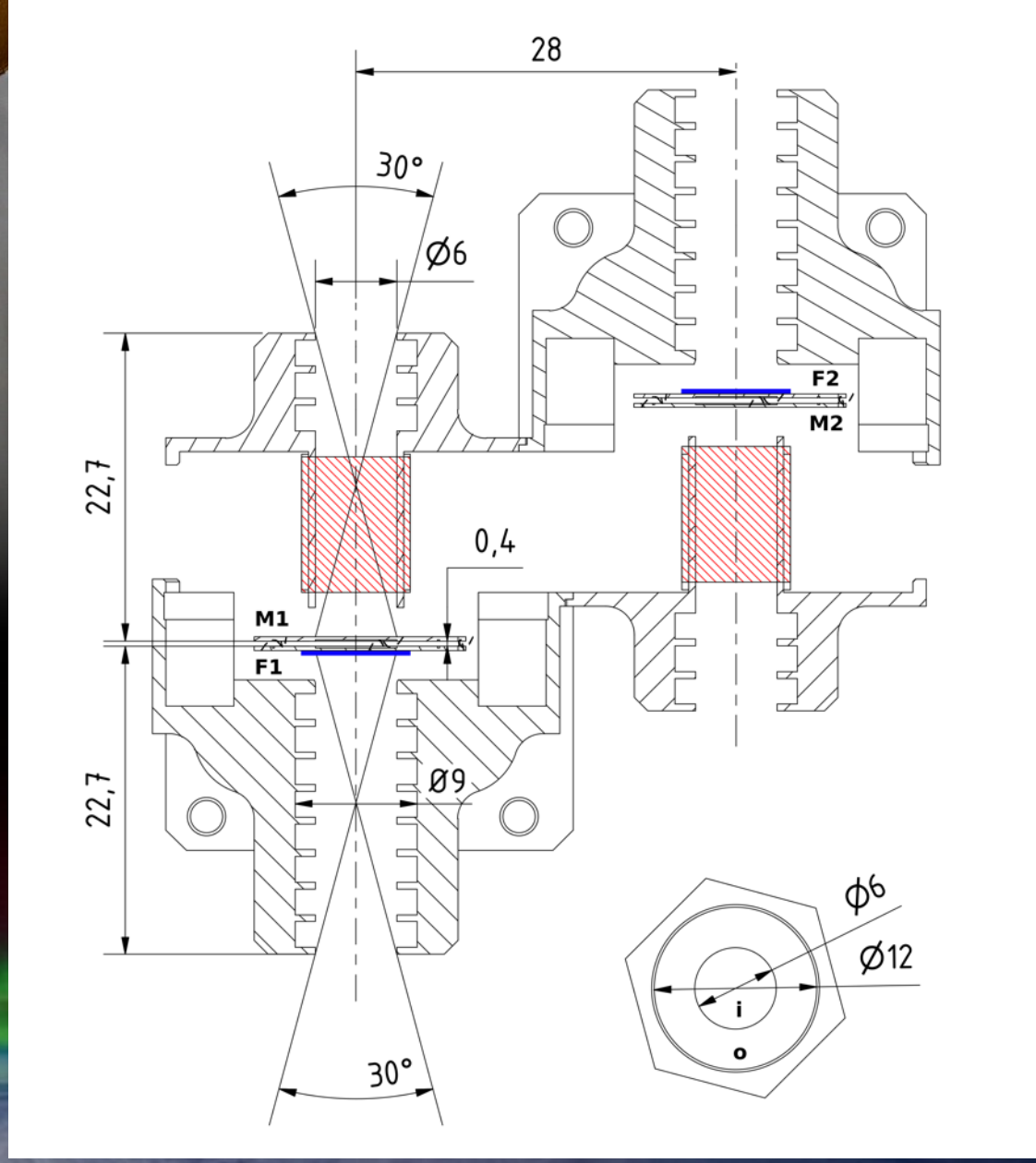



SIS
EPT-HET I
STEP
Z
Y
X

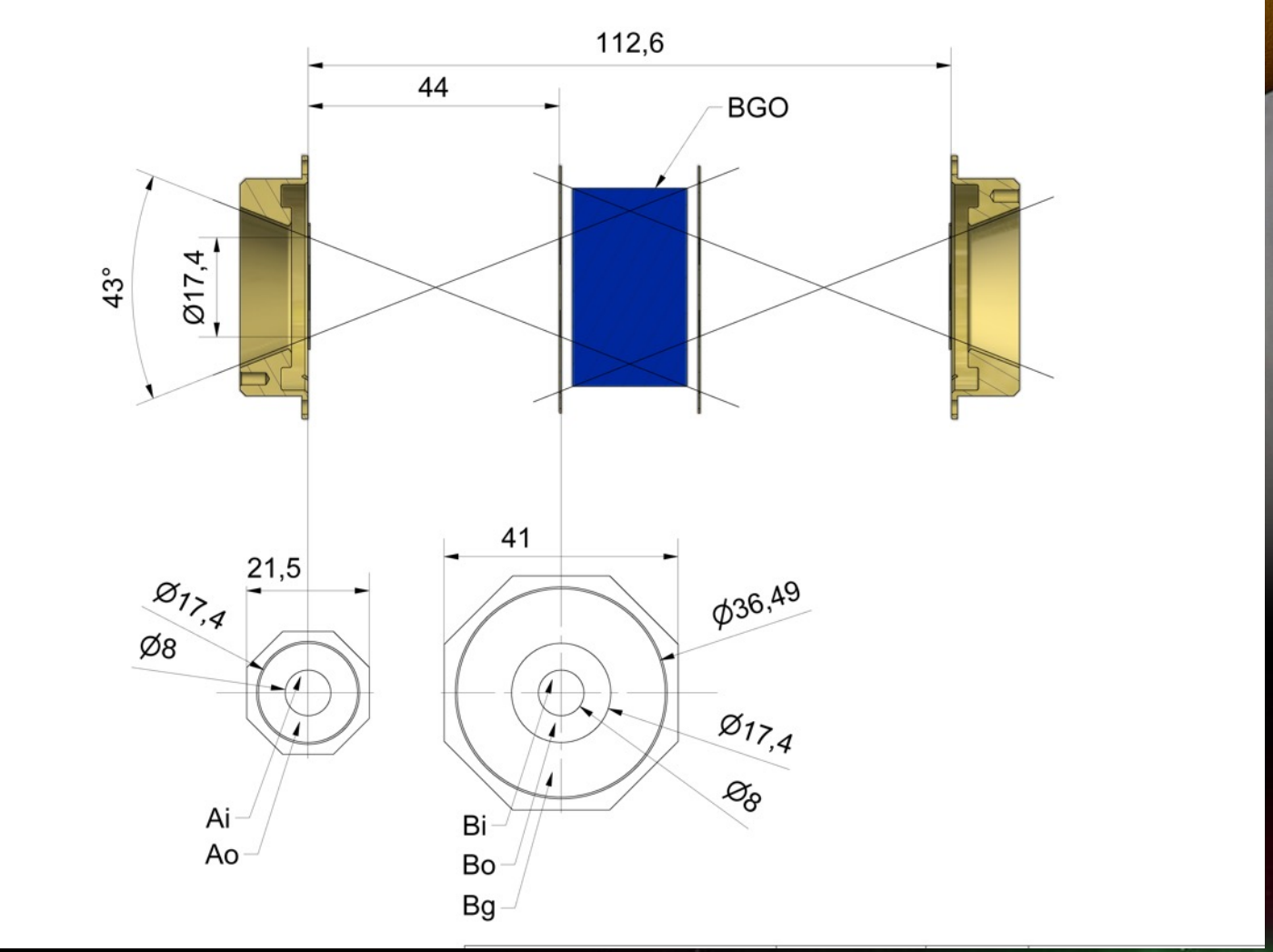

EPD
SIS
EPT/HET 2
ICU
13/07/2016
EPT/HET 1
STEP


Superposition of 5 keV proton FOVs (magnet and interal channels, side view)
z axis [mm]
10
0
−10
−30
−20
−10
0
10
20
30
200 keV electron trajectories in the magnet channel (side view)
z axis [mm]
x axis [mm]

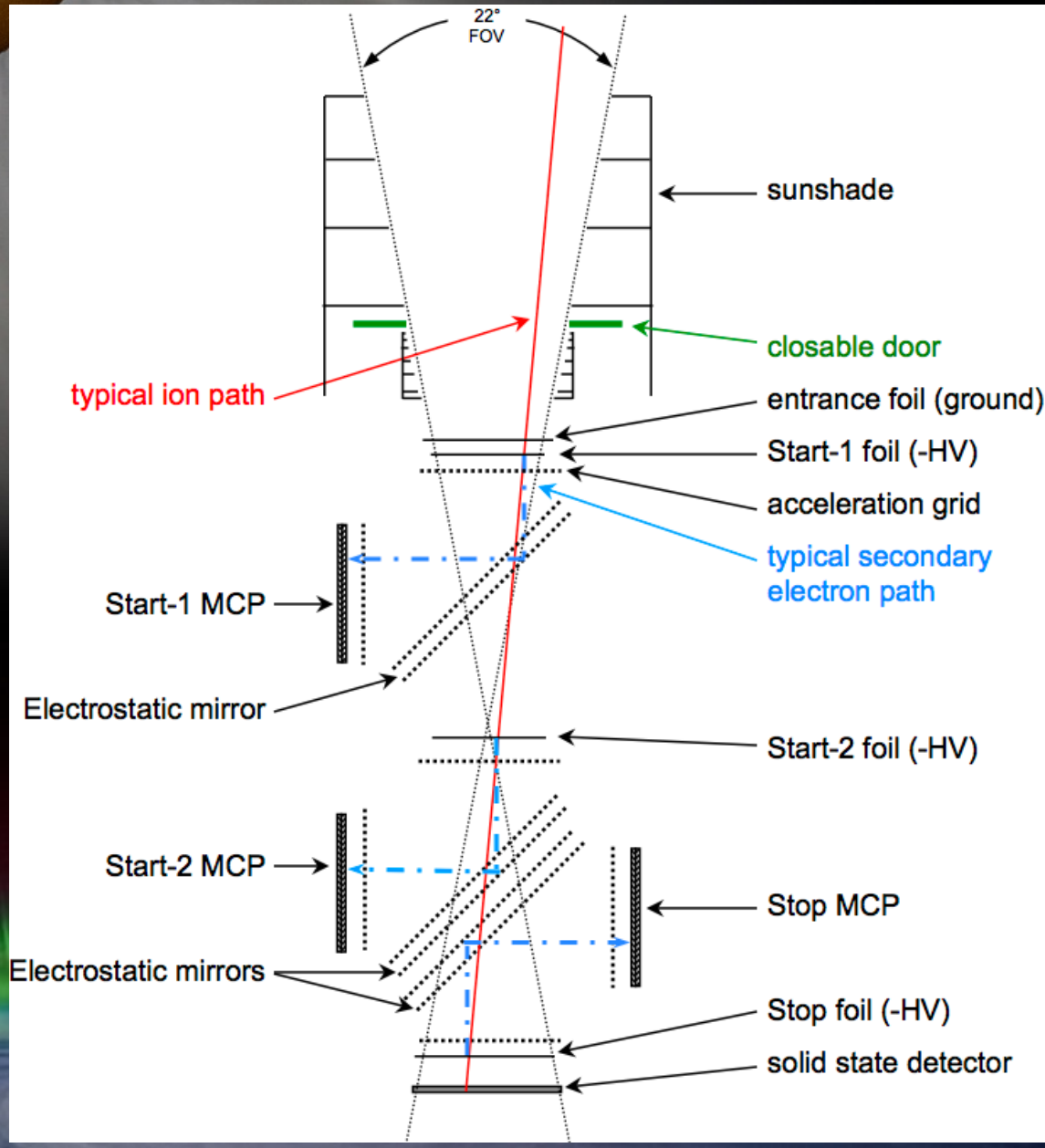
STEP


28
30°
Ø6
F2
M2
22,7
0,4
M1
F1
Ø9
22,7
30°
ϕ6
Ø12
i
o

EPT


112,6
44
BGO
43°
Ø17,4
21,5
41
Ø17,4
Ø8
ϕ36,49
Ø17,4
Ø8
Ai
Ao
Bi
Bo
Bg

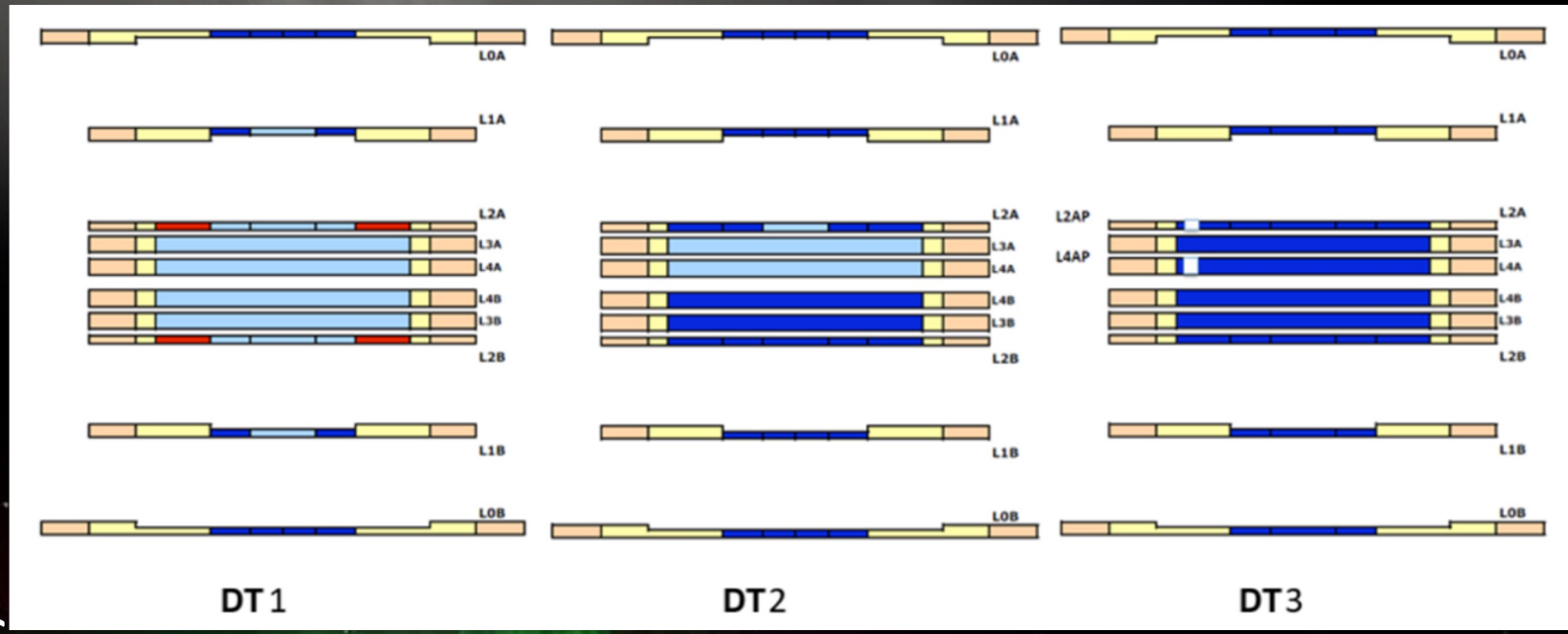
HET


22°
FOV
sunshade
closable door
typical ion path
entrance foil (ground)
Start-1 foil (-HV)
acceleration grid
typical secondary
electron path
Start-1 MCP
Electrostatic mirror
Start-2 foil (-HV)
Start-2 MCP
Stop MCP
Electrostatic mirrors
Stop foil (-HV)
solid state detector

SIS

Considerations in using data

- Mode of instrument
- Saturation
  - Livetime
  - Pileup
- Background
- Pointing not nominal
  - PSP pointing, mag rolls
  - STEREO flipped for coms



Considerations in using data

- Mode of instrument
- Saturation
  - Livetime
  - Pileup
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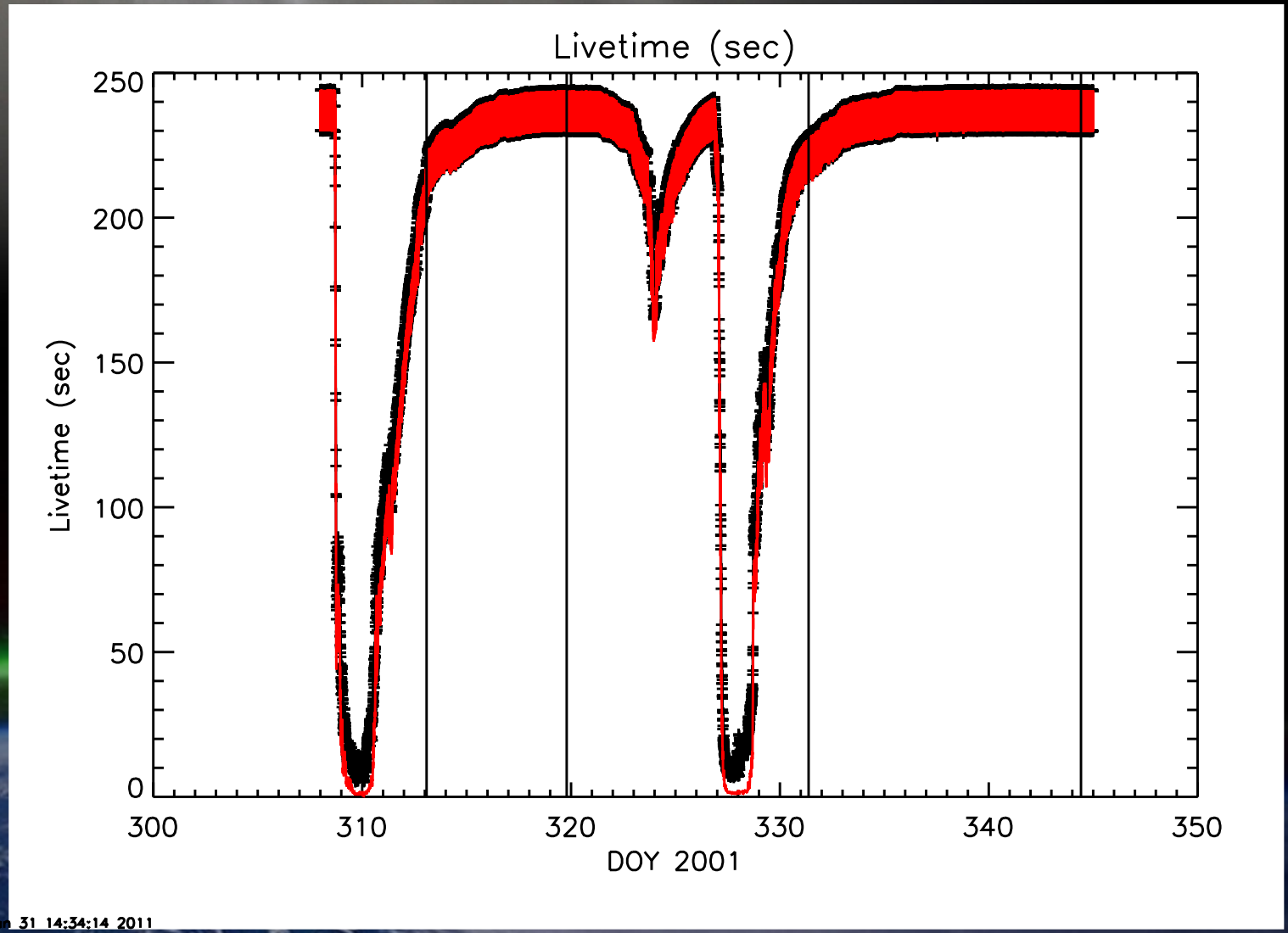
- Pointing not nominal
  - PSP pointing, mag rolls
  - STEREO flipped for coms



Considerations in using data

- Mode of instrument
- Saturation
  - Livetime
  - Pileup
- Background
- Pointing not nominal
  - PSP pointing, mag rolls
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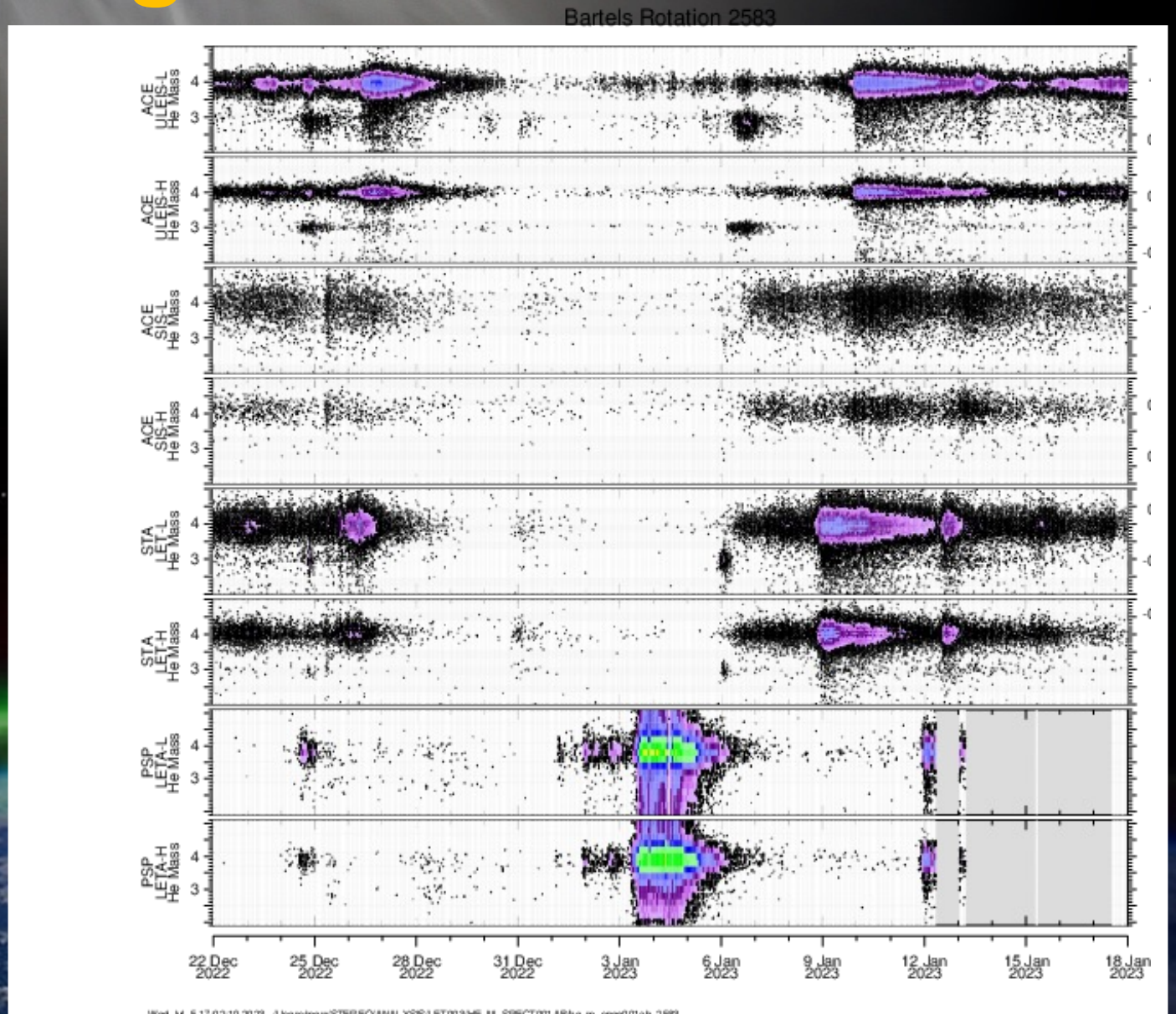

Considerations in using data

- Mode of instrument
- Saturation
  - Livetime
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- Background
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